Search for CP violation in single top

- Motivation
- Measuring single top production cross section
- Search for CP violation in single top
- Summary

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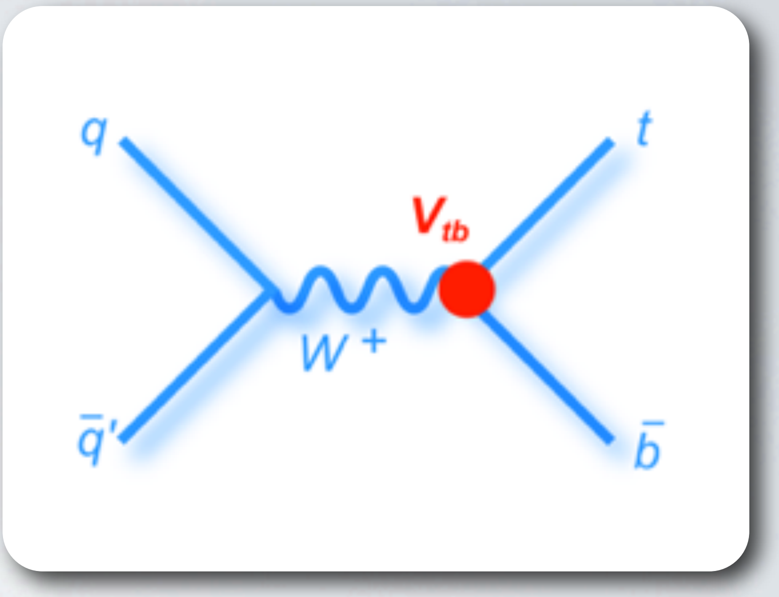
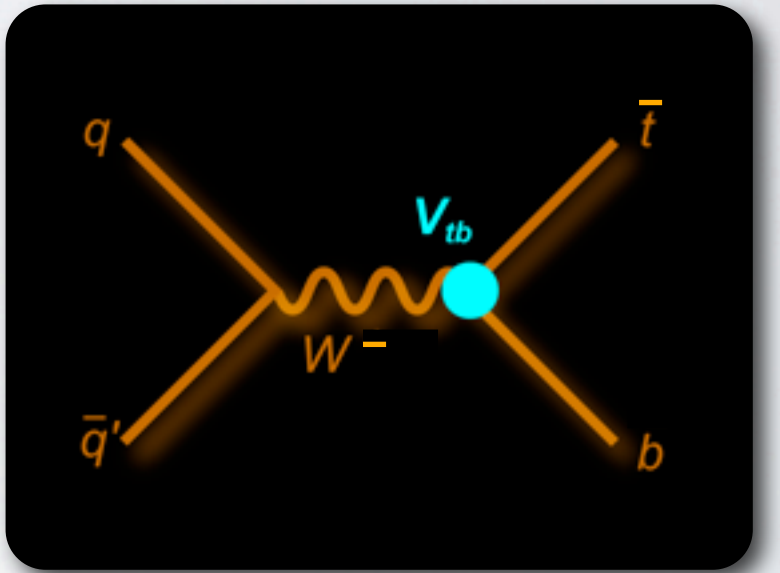
Motivation

- Within standard model (SM) top physics can accommodate negligible amount of CP violation.
- In contrast several BSM scenarios can produce significant CP violation.
- In the case of single top this will result in different production rate between top and antitop of the other of few percents.
- The common models for these scenarios are some version of 2,3DHM and SUSY.
- However, expected sensitivity to measure differences in single top production rate are of tens of percents.
- Therefore, the current proposal is based on model-independent search.

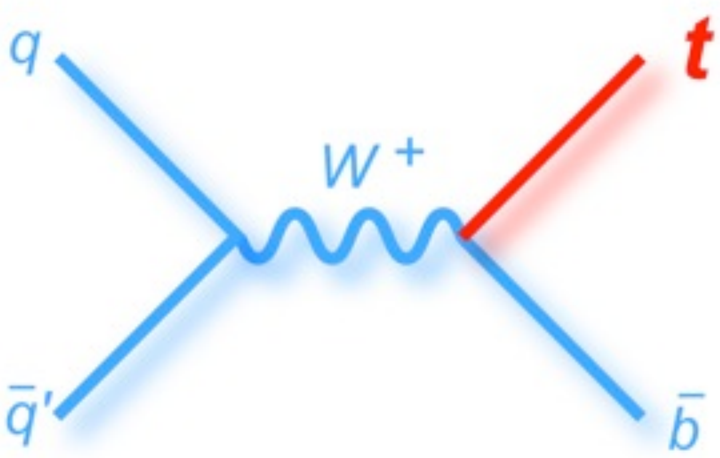




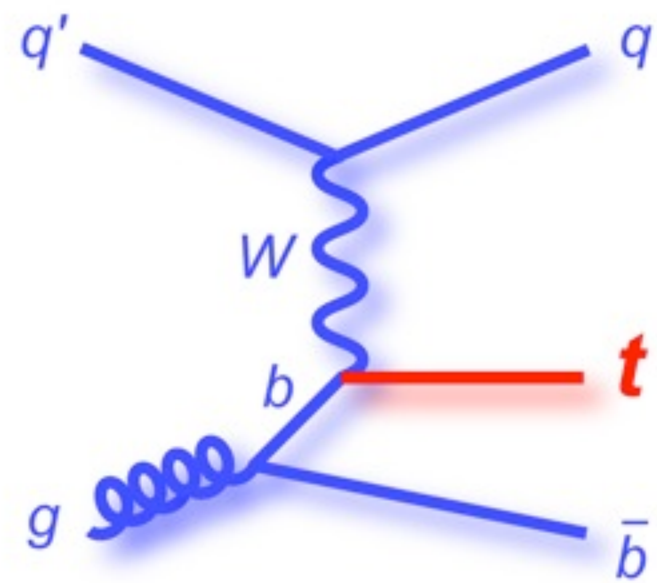
Mod. Phys. Lett. A 10 627 (1995)
Phys. Rev. D 54, 5412 (1996)
Phys. Rept. 347, 1 (2001)

Single top production channels

s-channel (tb)

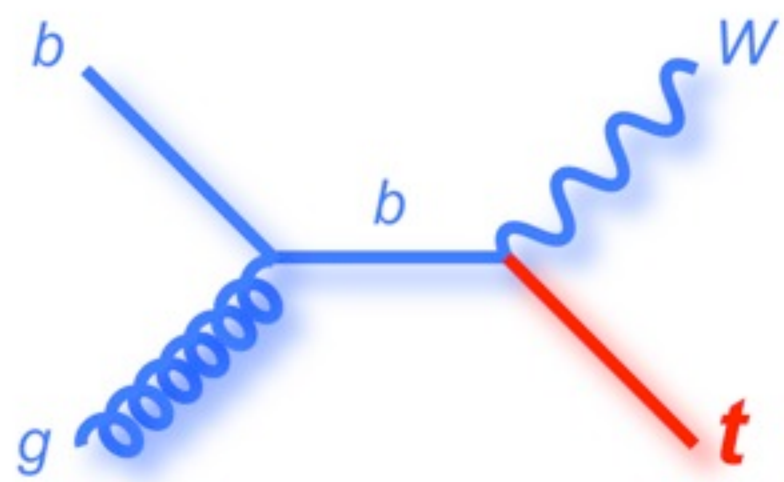


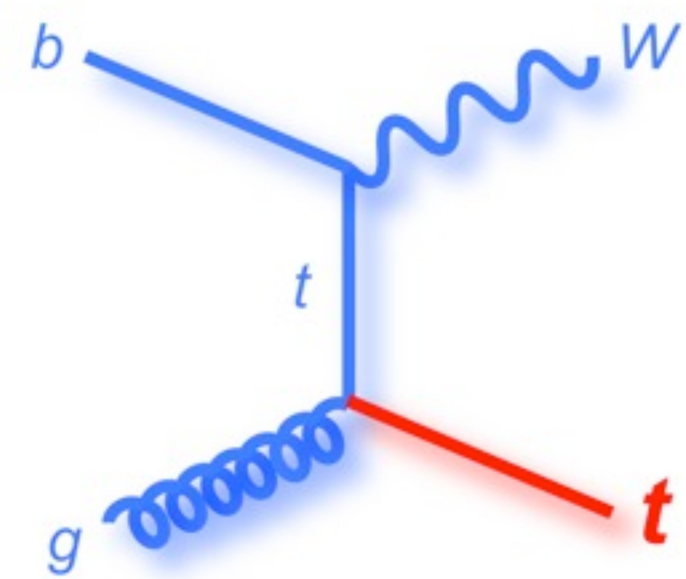
t-channel (tqb)



Main production at Tevatron

Associated tW





- Production channels at hadron colliders.
- Difference between Tevatron and LHC is the relative contribution of to each production channel.

Single top cross section

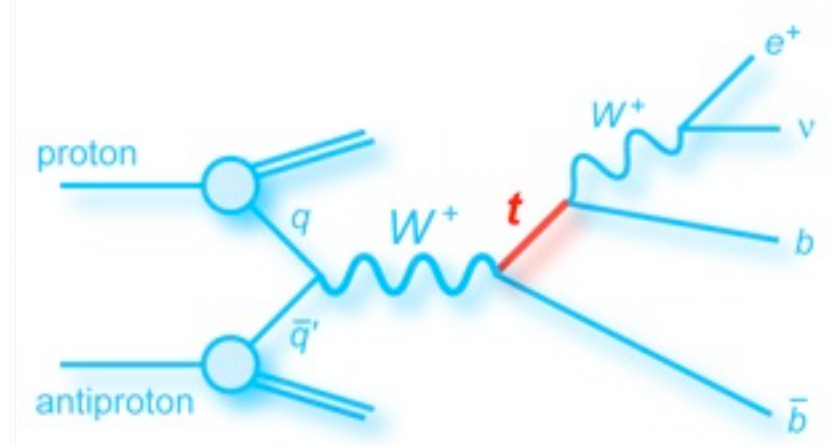
- Expect an enhancements of x31(117) and x26(139) for t-channel and tW productions between Tevatron and LHC@7(14)GeV.
- However, for s-channel the xsection is only increase x4.5(11).
- Note that the xsection for top and antitop are not the same at LHC.

m_t = 173 GeV m_t = 172.5 GeV	s NNLO	t NNLO	tW NNLO
	t+tbar = total [pb]	t+tbar = total [pb]	t+tbar = total [pb]
Tevatron (1.96 TeV)	1.04	2.26	0.30
LHC (7 TeV)	3.17 + 1.42 = 4.59	41.7 + 22.5 = 64.2	7.8
LHC (14 TeV)	7.93 + 3.99 = 11.92	151 + 92 = 243	41.8

Kidonakis arxiv:1008.2460; Phys.Rev.D83,091503; arxiv:1105.3481

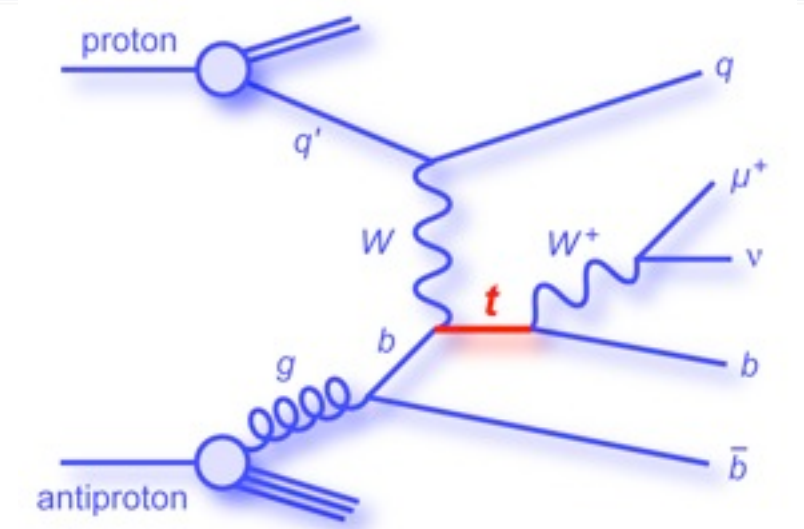
Event Selection

- A dataset of 5.4 fb-1.
- One high-pT isolated electron or muon.
  - $p_T > 15GeV, |\eta| < 1.1(e) < 2.0(\mu)$
- Large missing transverse energy.
  - $\not{E}_T > 20\text{GeV}$
- Two, three and four jets.
  - $p_T > 25$ GeV (jet1), > 15 GeV (other jets)
  - $|\eta_{\text{det}}| < 3.4$
- Total transverse energy and triangular cuts.
  - $H_T > 110 - 160$ GeV
  - $|\Delta\phi(\text{jet1}, \not{E}_T)|$ vs $\not{E}_T$, $|\Delta\phi(\text{lepton}, \not{E}_T)|$ vs $\not{E}_T$
- b-jet identification:
  - One “tight” b-tagged jet or two “loose” b-tagged jets



s-channel

$\sigma_{SM} = 1.04 \pm 0.04$ pb



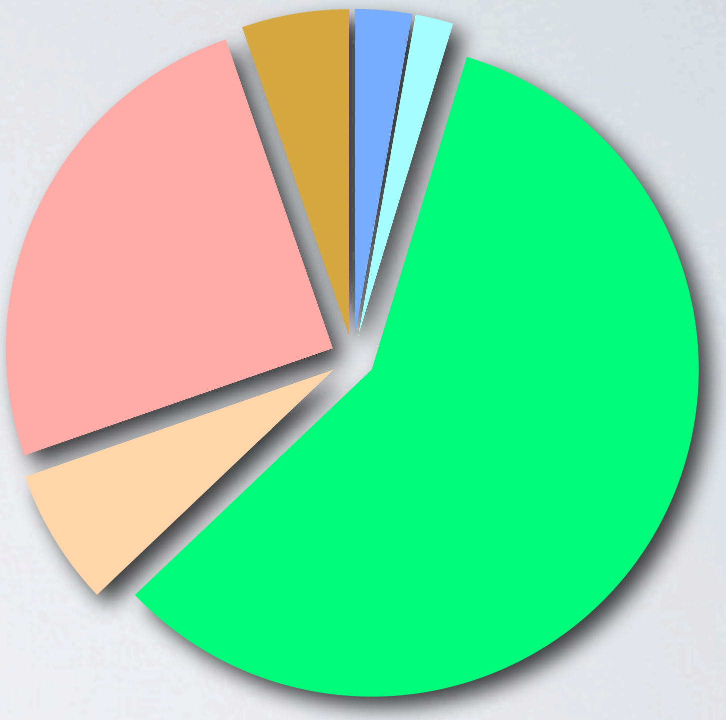
t-channel

$\sigma_{SM} = 2.26 \pm 0.12$ pb

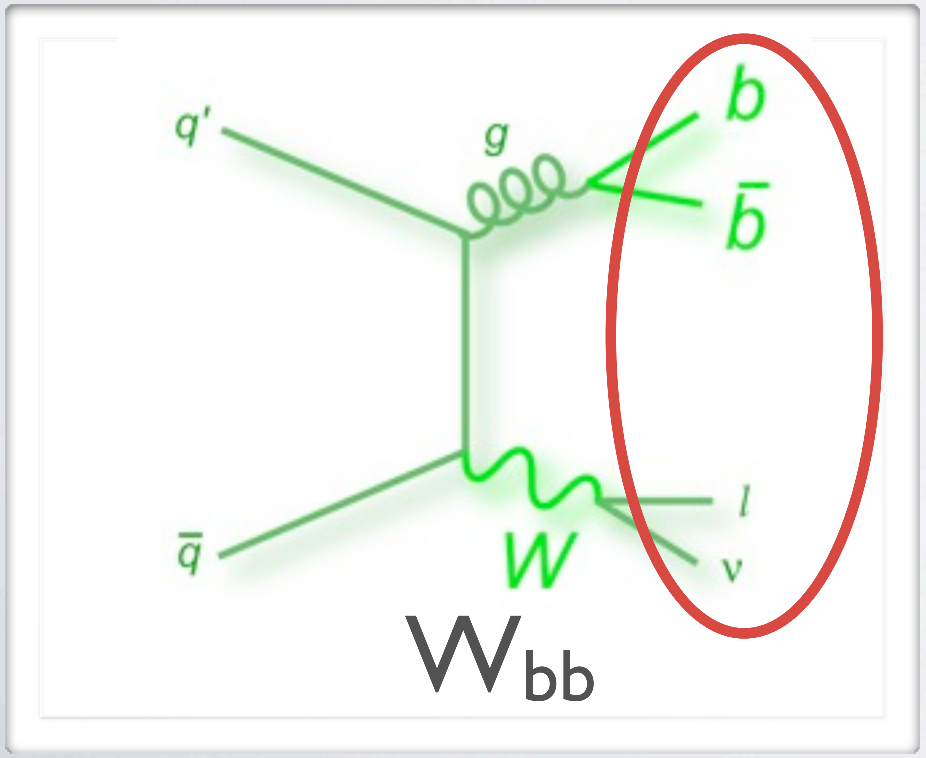
Challenge of the analysis

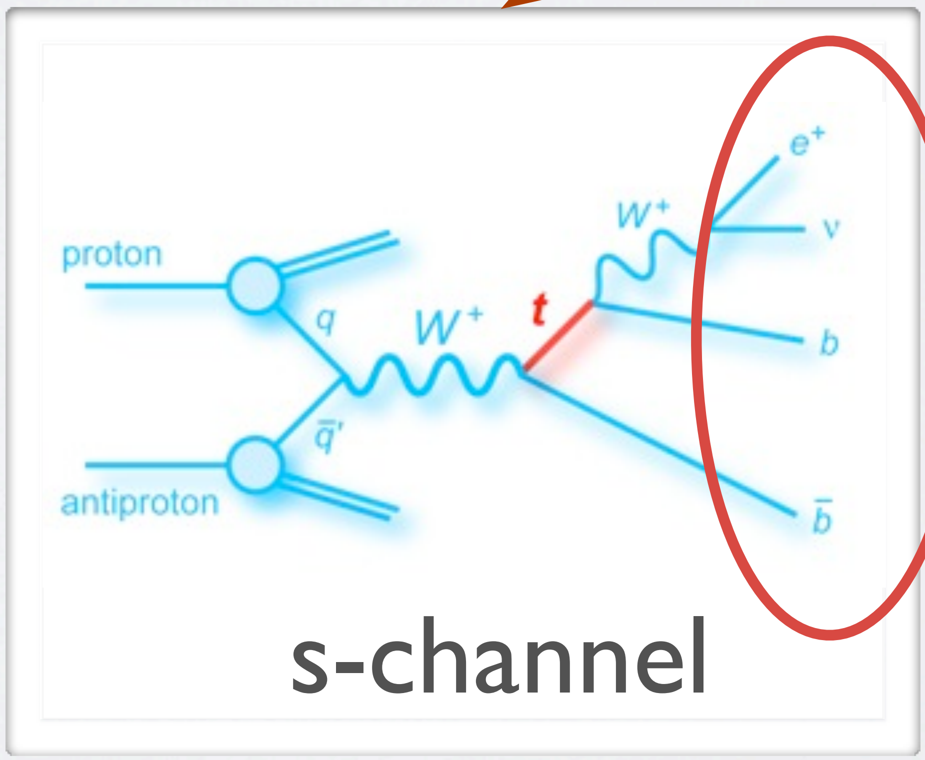
- Observed at the Tevatron with more than ~50 times the integrated luminosity used for observation of the top quark produced by strong interaction.
- Smaller cross section ~ 1/2 ttbar.
- Single top is mostly present in events with two and three jets.
- Background dominated after b-jet identification S:B ~ 1:20.
- This is because some backgrounds have similar final states.

S:B~1:20

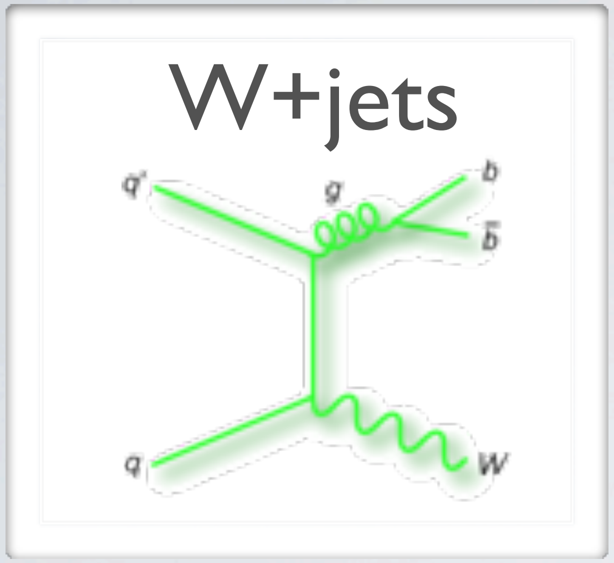


t-channel
s-channel
W+jets
Z+jet, dibosons
tt
Multijets

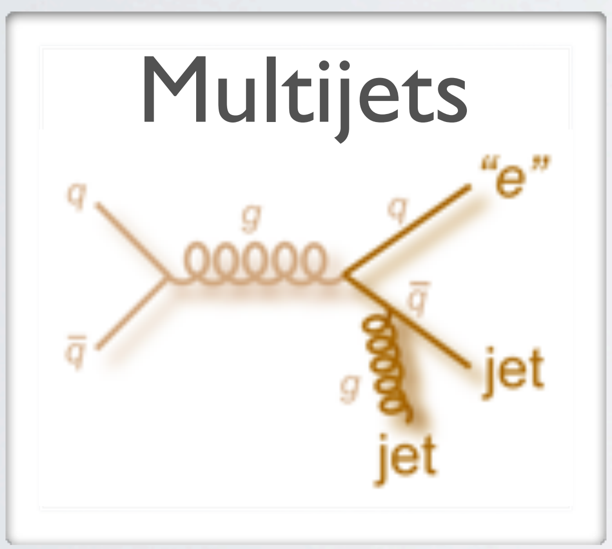




Backgrounds and Event yields



Modeled by Alpgen
Kinematics corrected to data
Normalized to data

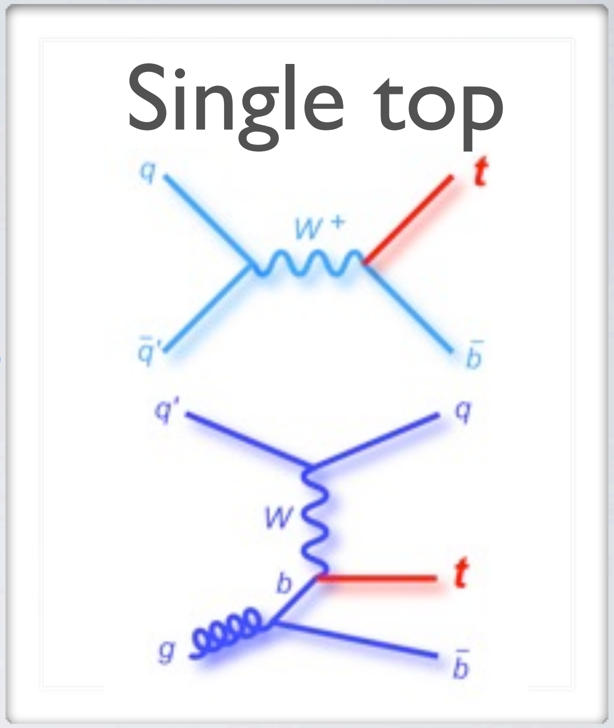


Modeled using data
Normalized to data

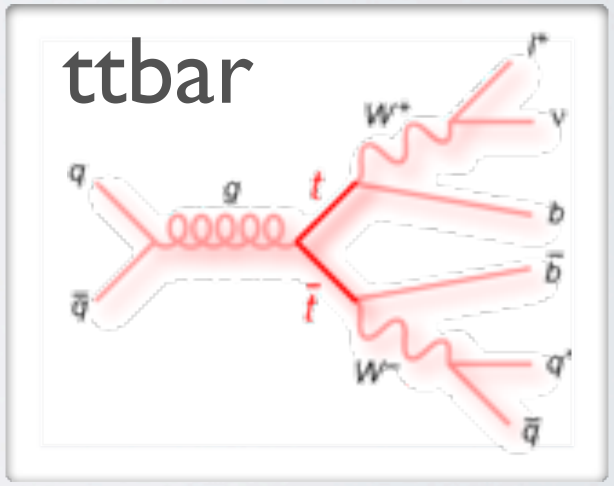
Event yields in 5.4/fb DØ data

e,μ, 2,3,4-jets 1,2-tags combined

t-channel	239 ± 28
s-channel	160 ± 27
W+jets	4943 ± 598
Z+jet, dibosons	576 ± 113
tt	2124 ± 383
Multijets	451 ± 56
Total prediction	8492 ± 987
Data	8471 ± 92



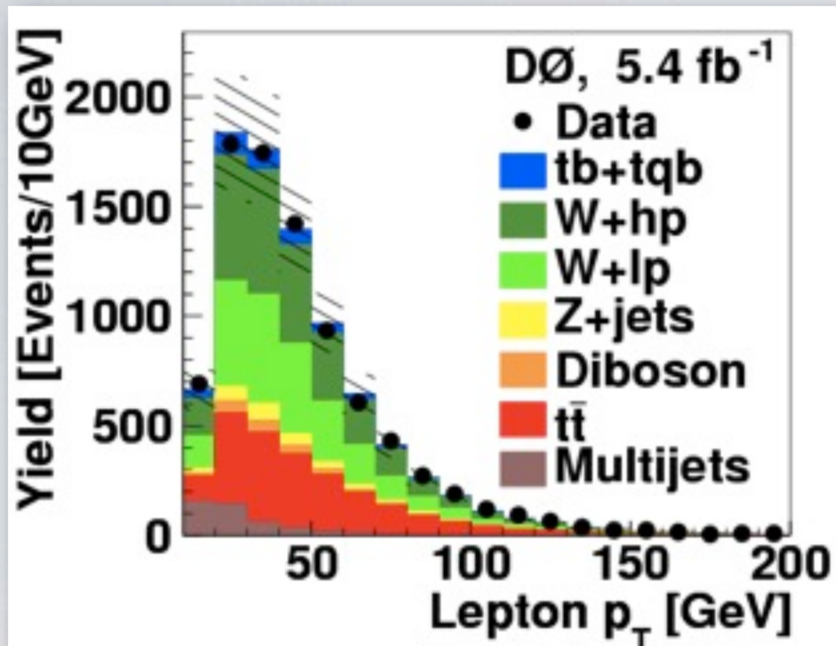
Modeled using Comphep
Normalized to NNLO

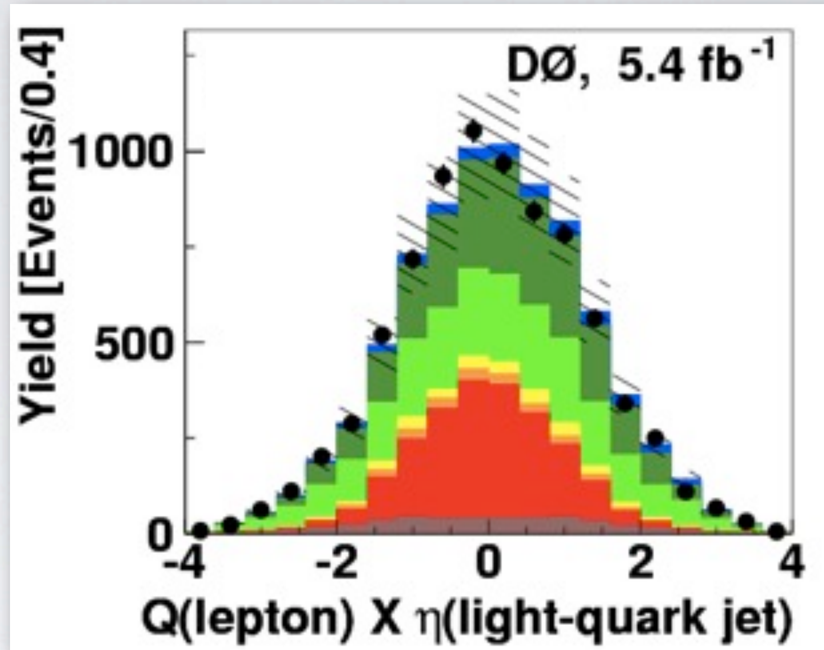


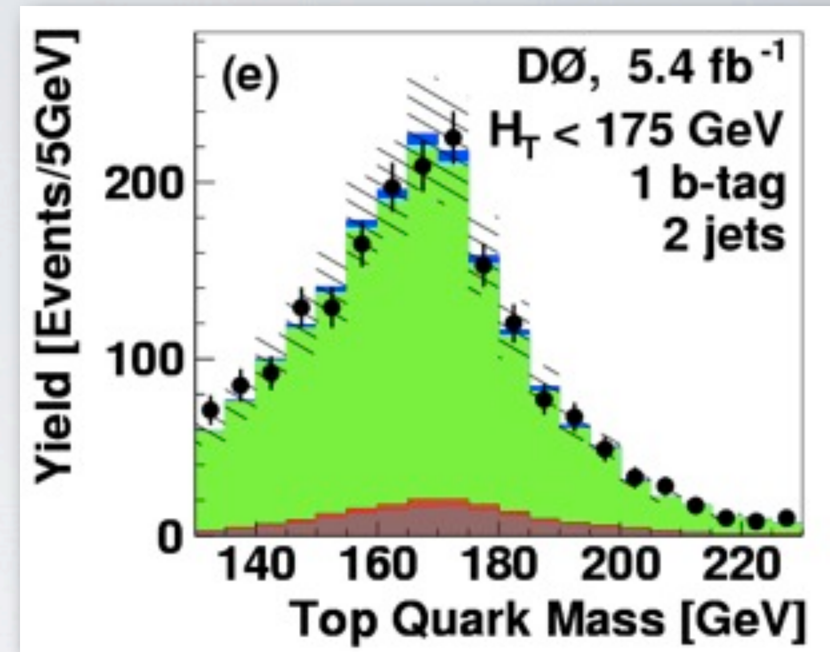
Modeled using Alpgen
Normalized to ~NNLO

Background modeling

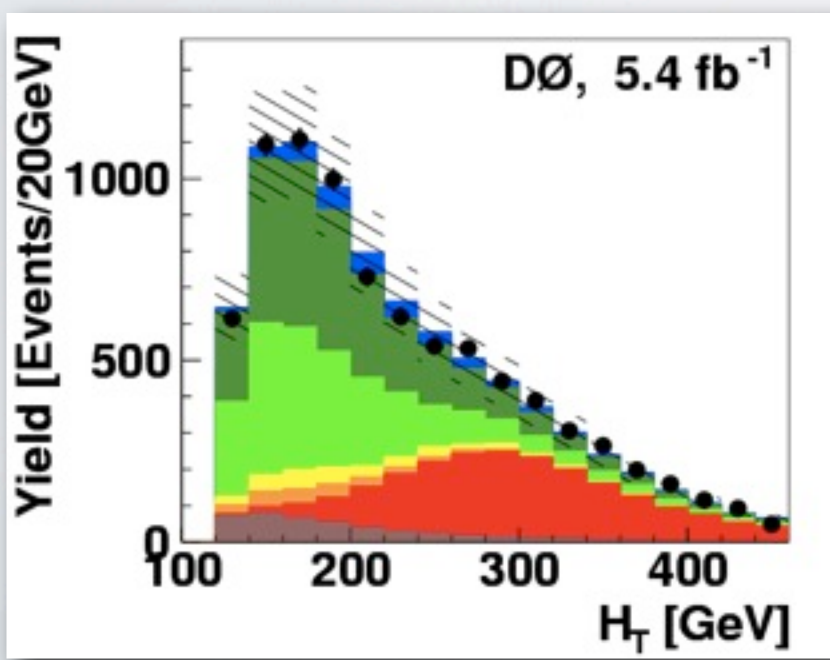
w+jets enriched

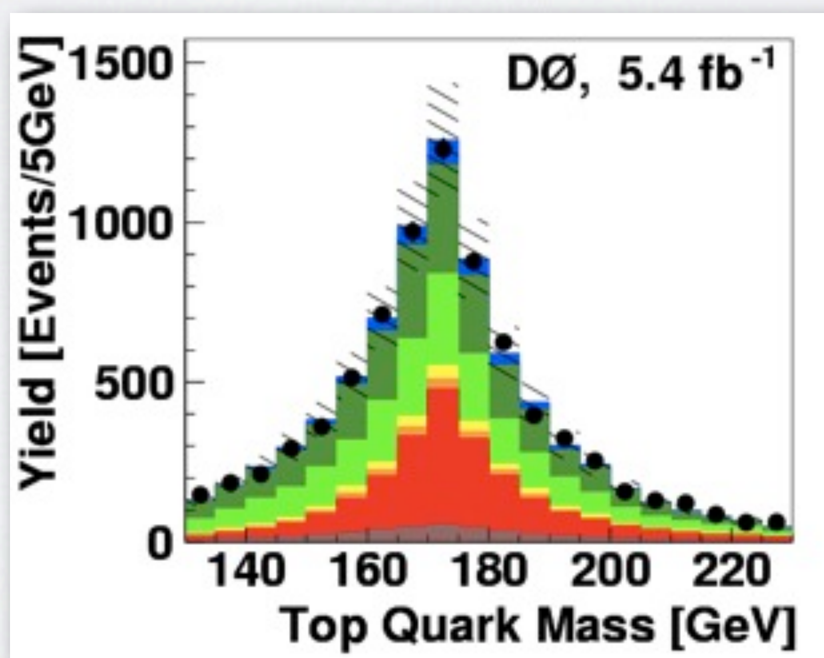


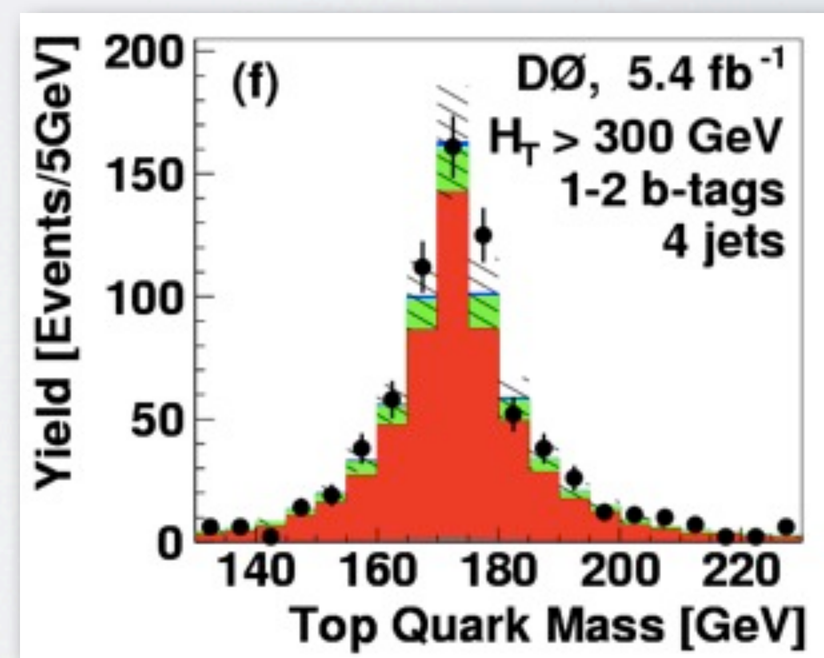




ttbar enriched

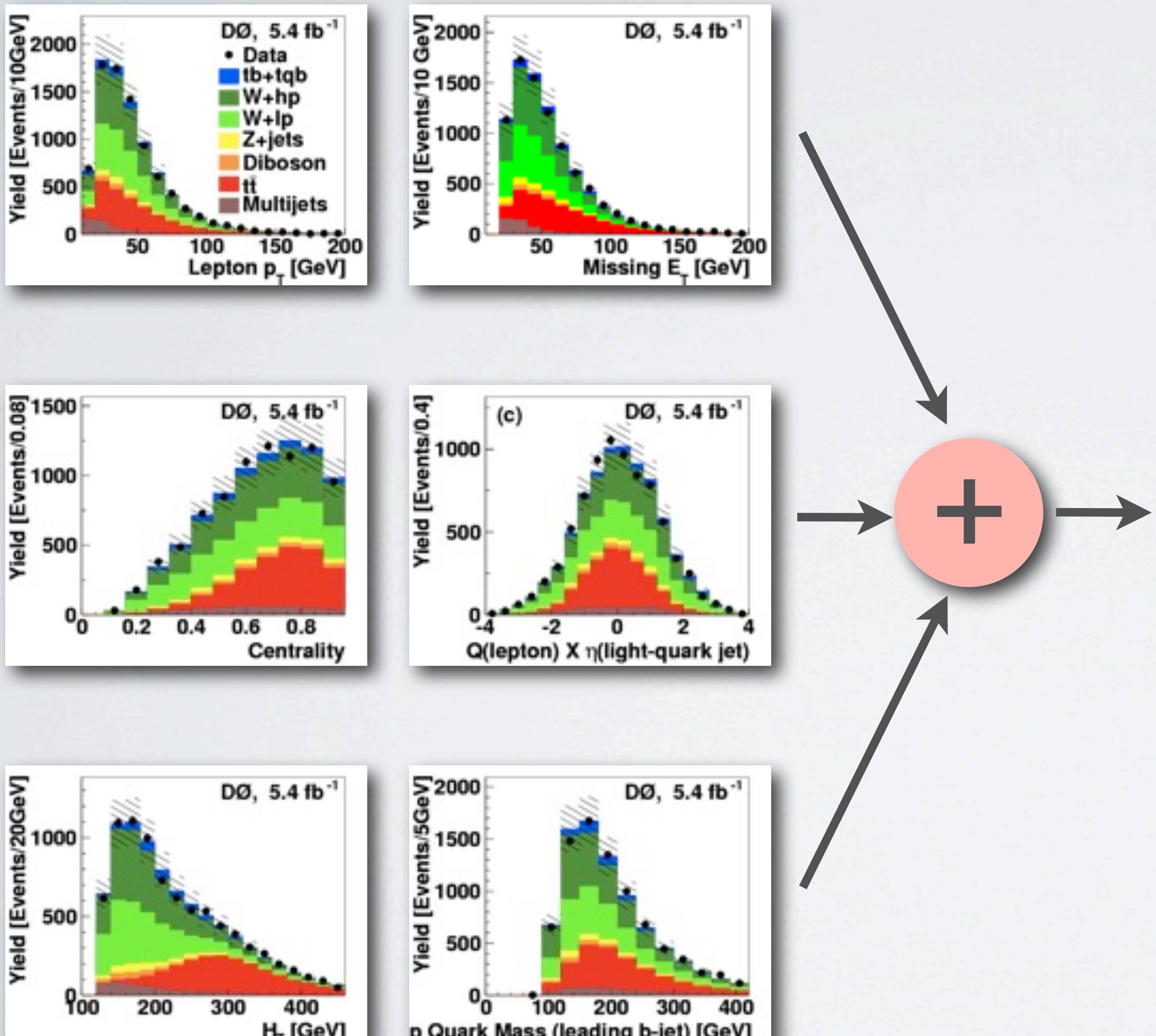




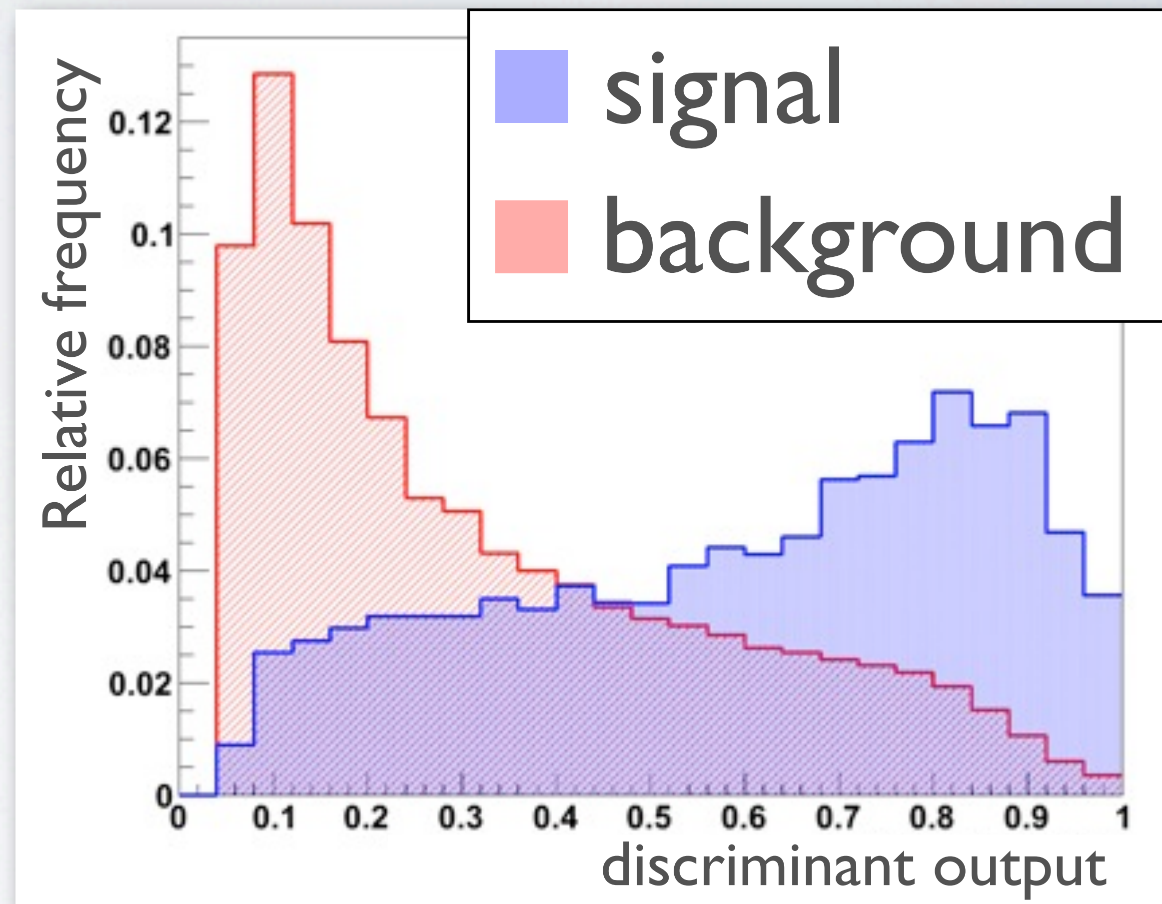


Multivariate Analyses

Combined different kinematic variables with some discrimination power into one variable with larger discrimination.



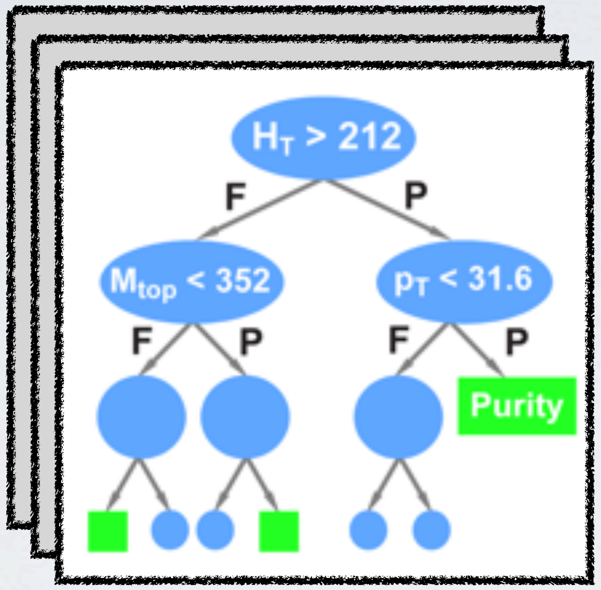
After training



Multivariate analyses

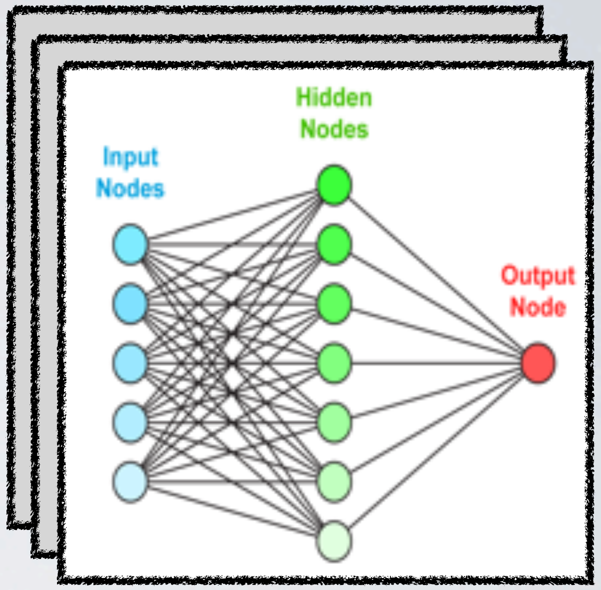
Boosted Decision Tree (BDT)

- Apply sequential cuts keeping failing events.
- Performance is boosted by averaging multiple trees produced by enhancing misclassified events.



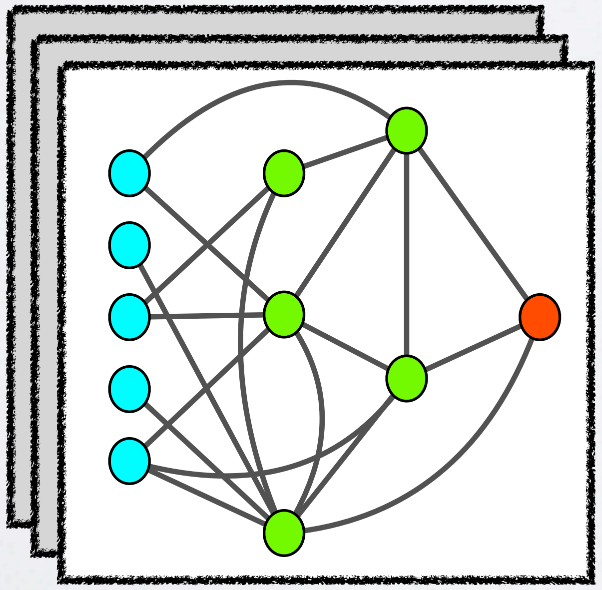
Neural Networks (BNN)

- Bayesian NN (BNN) averaged over many networks, improving the performance.



Neuroevolution of Augmenting Topologies (NEAT)

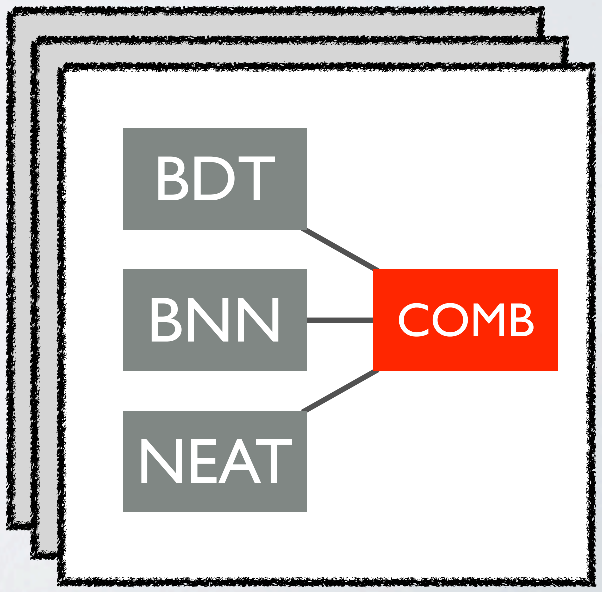
- Genetic algorithms evolve a population of NN.
- Topology of the NN is also part of the training.



BNN Combination

Correlation between methods ~70%

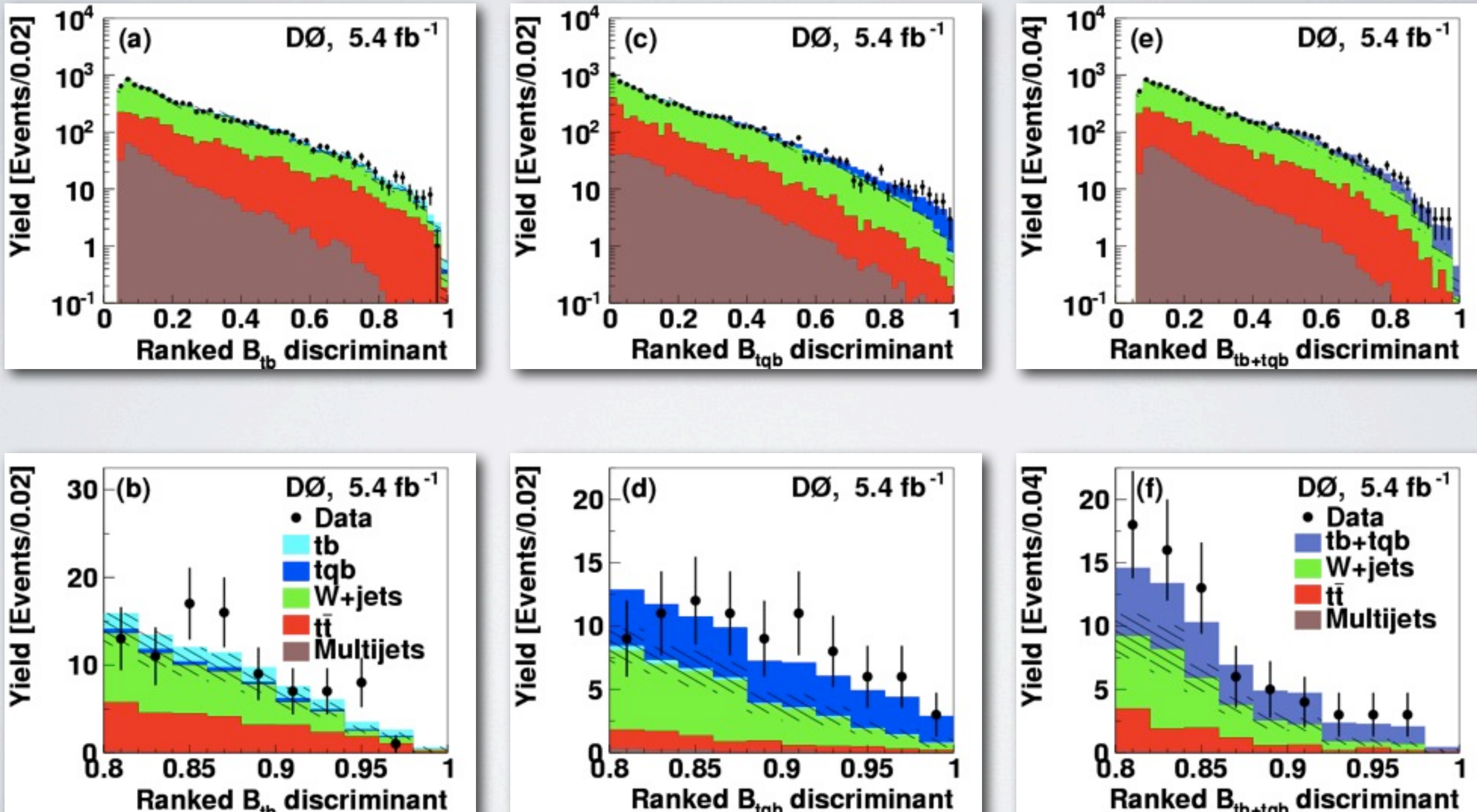
- Different discriminants are combined into one.



MVA outputs

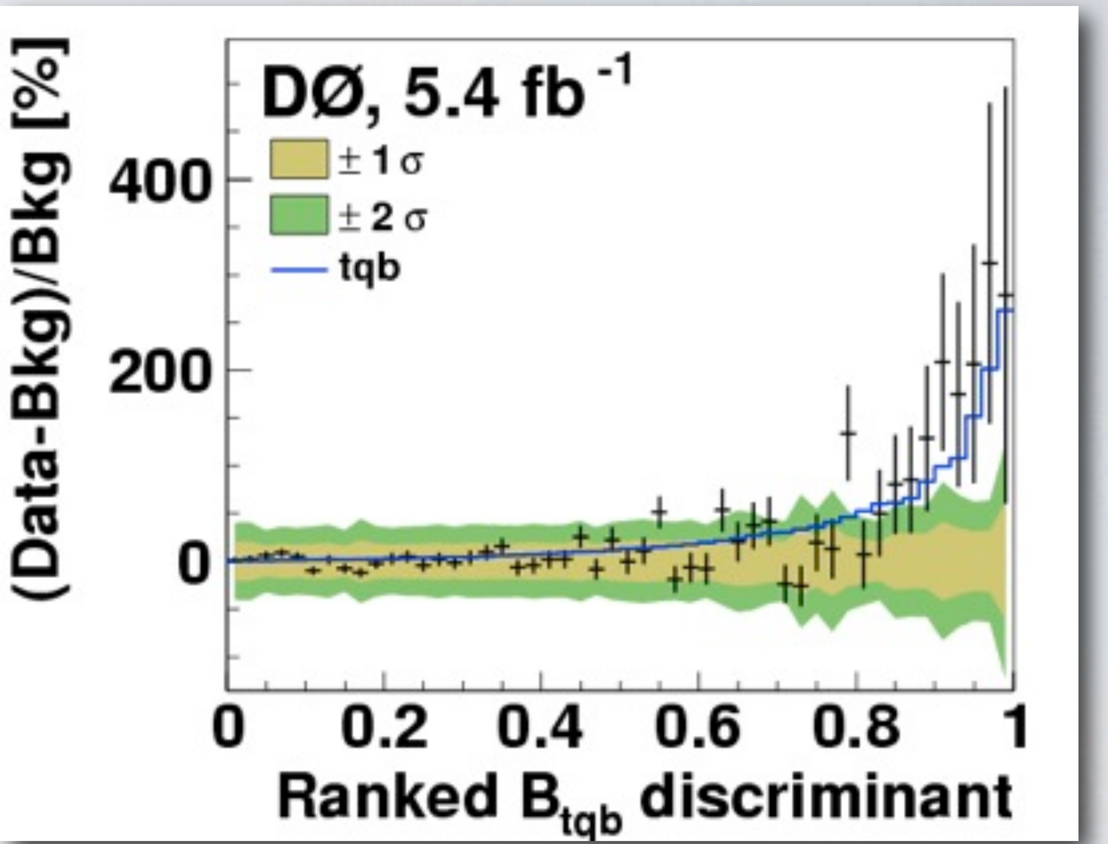
new

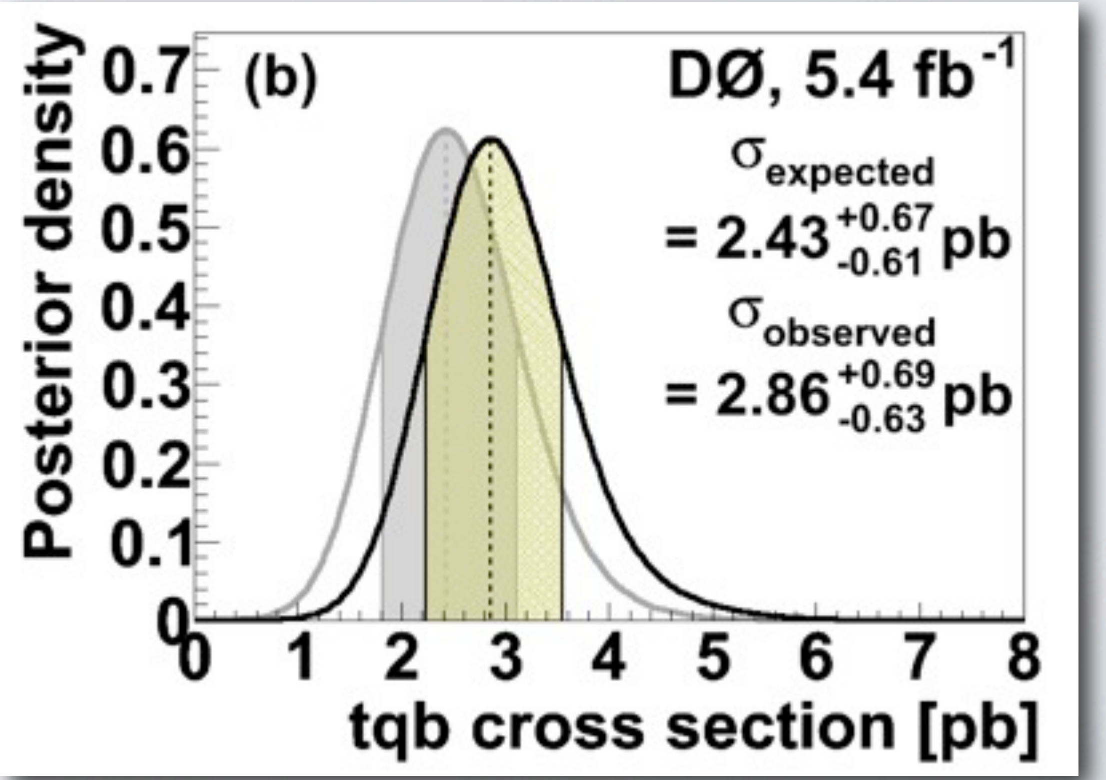
tb discriminant | tqb discriminant | tb+tqb discriminant



Measuring cross section

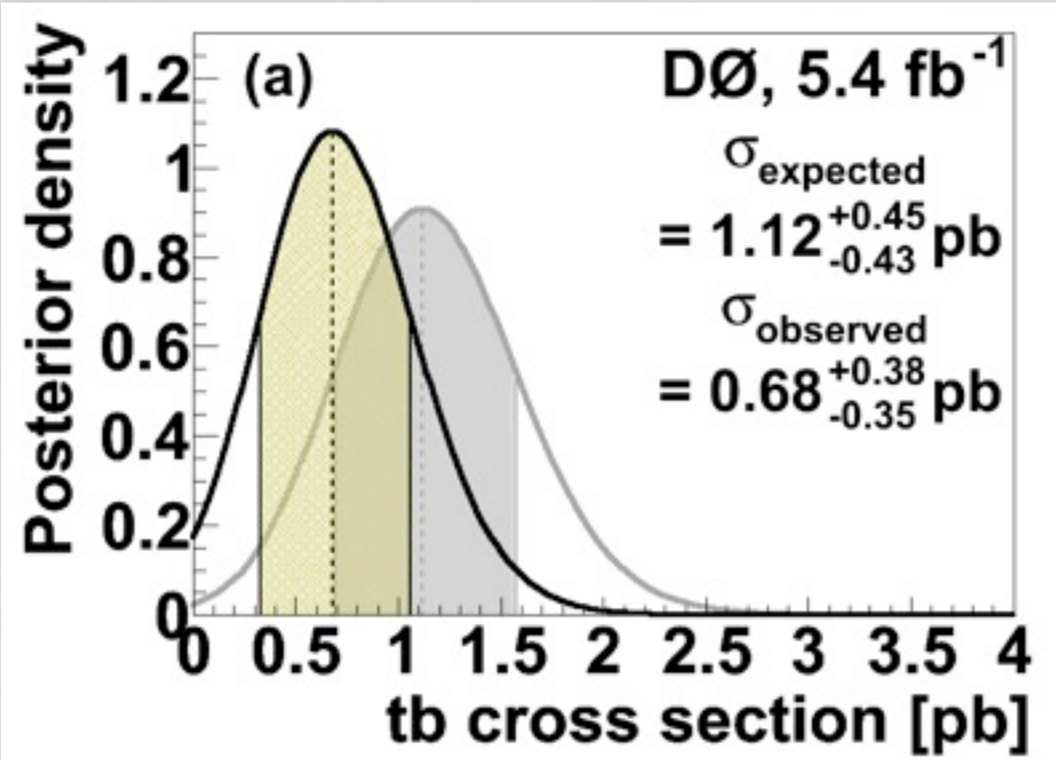
- Using a discriminant is possible to define a binned likelihood.
- Cross sections are measured by building a Bayesian posterior probability density.
- For each analysis, the single top cross section is given by the position of the posterior density peak, with 68% asymmetric interval as uncertainty.
- Gaussian prior for systematic uncertainties.
- Correlations of uncertainties properly taken into account.
- Flat prior in signal cross sections.
- The largest uncertainties come from the jet energy scale and resolution, corrections to the b tagging efficiency, and the corrections for the jet flavor composition in W+jets events.

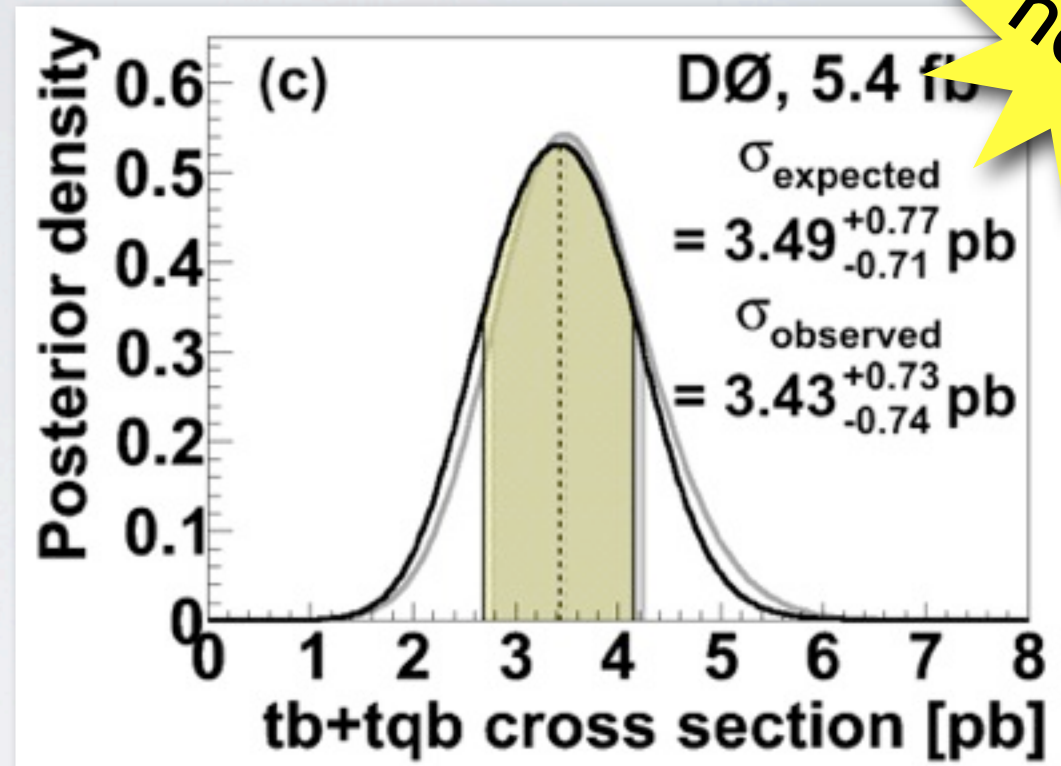


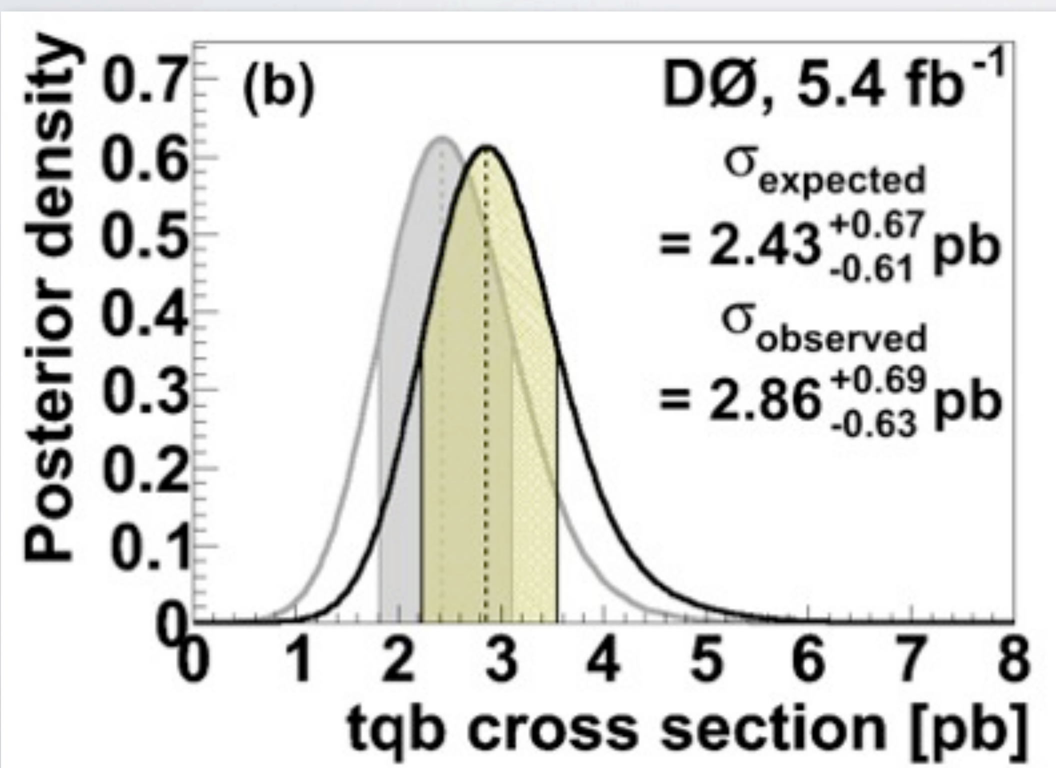


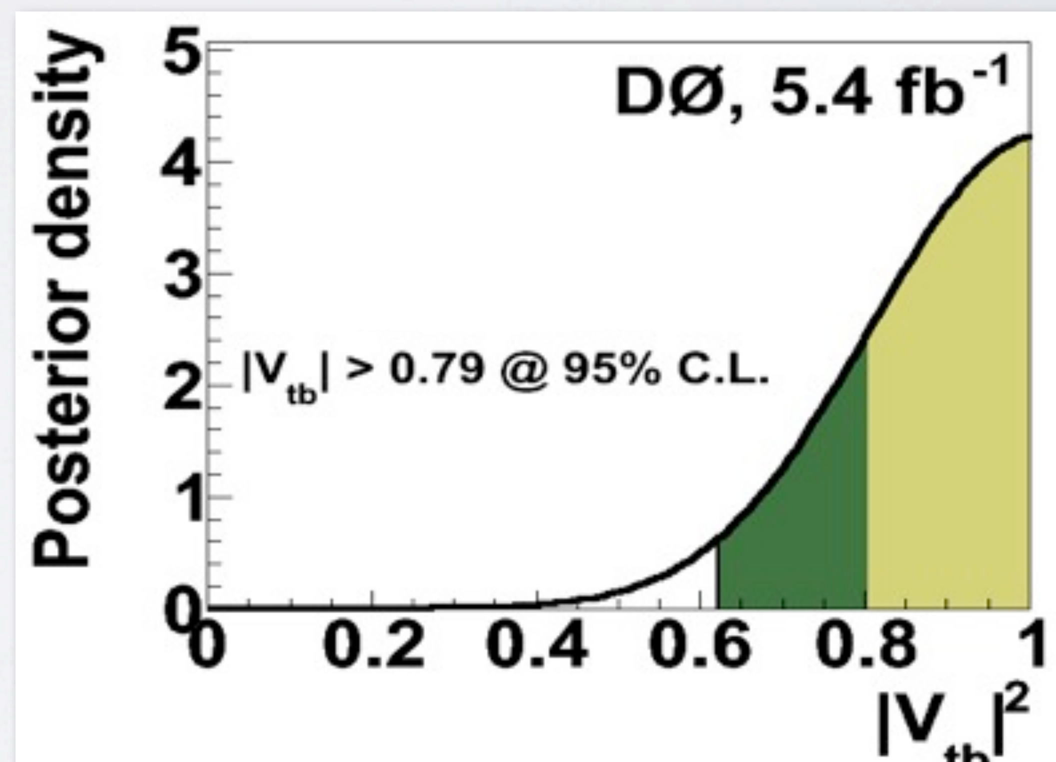
Single top cross section measurements

new







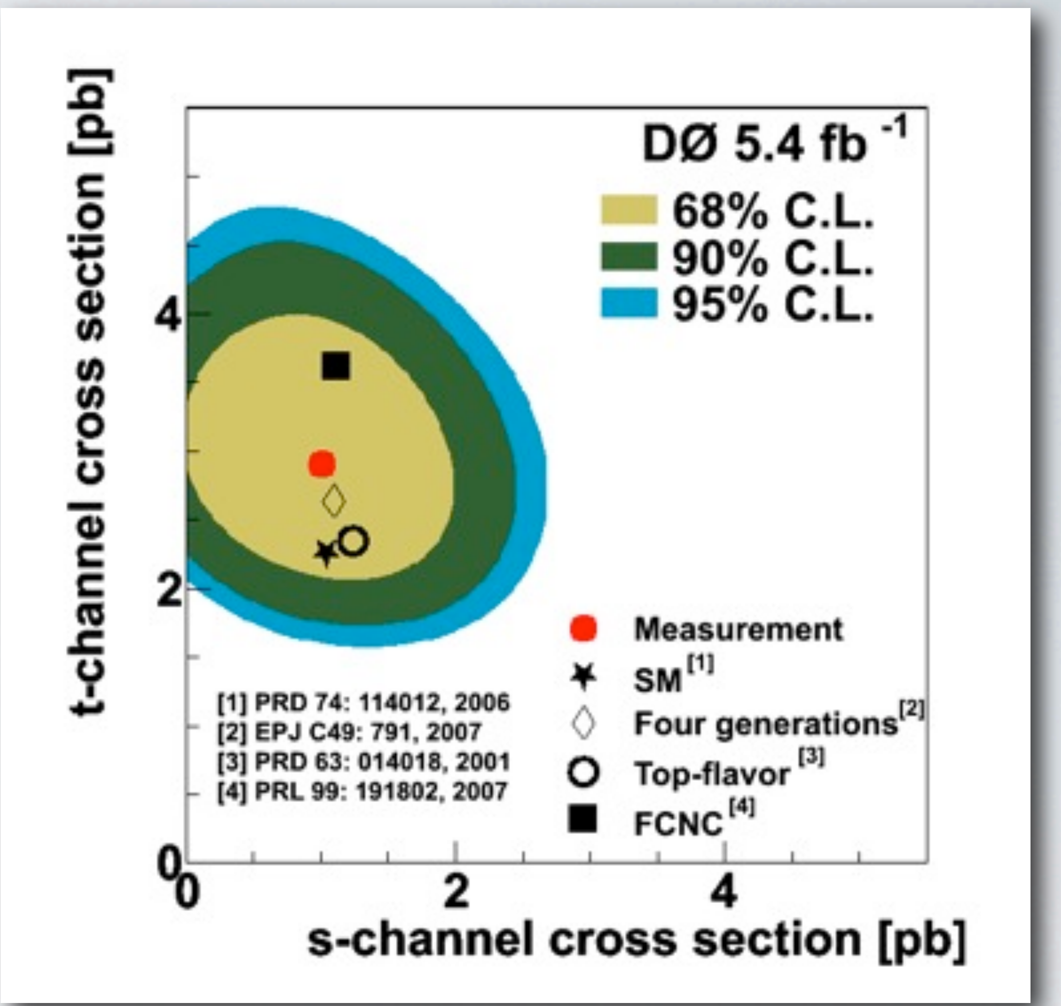


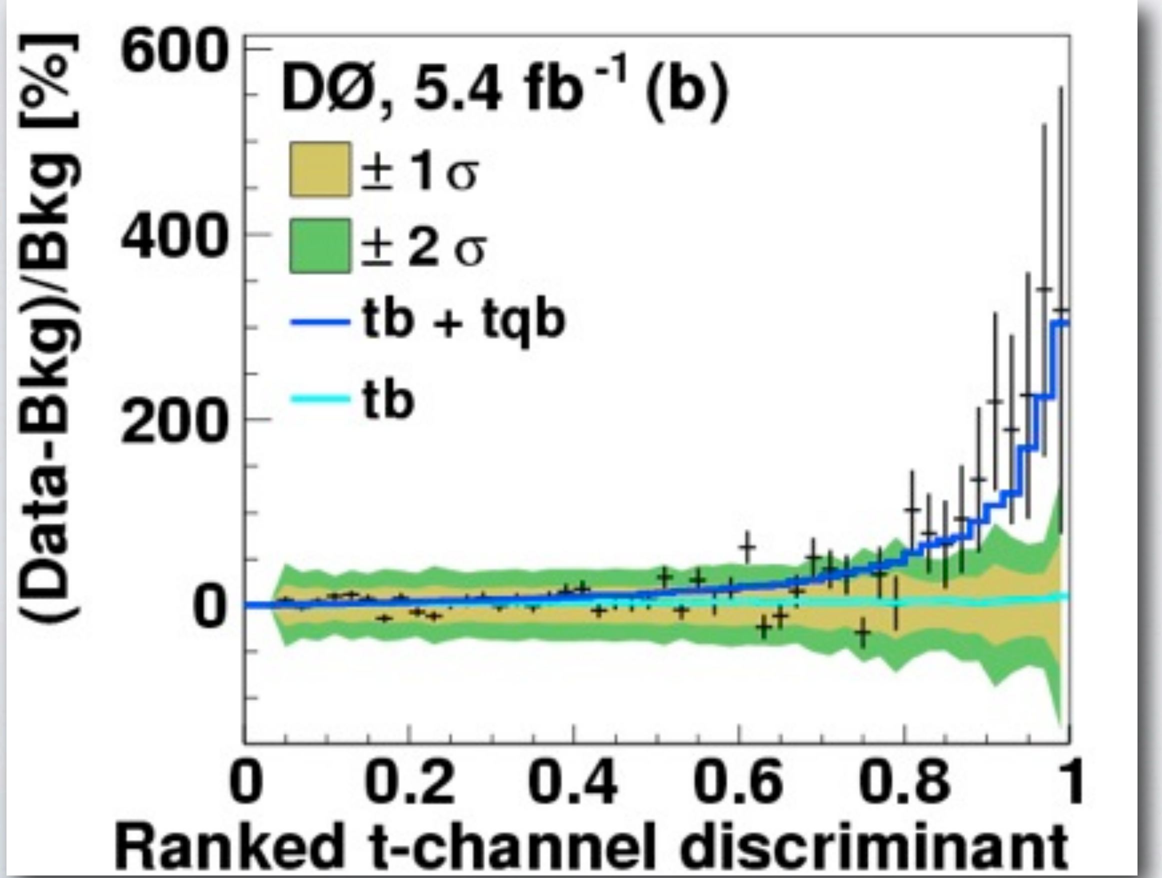
arXiv:1108.3091 submitted to Phys. Rev. D

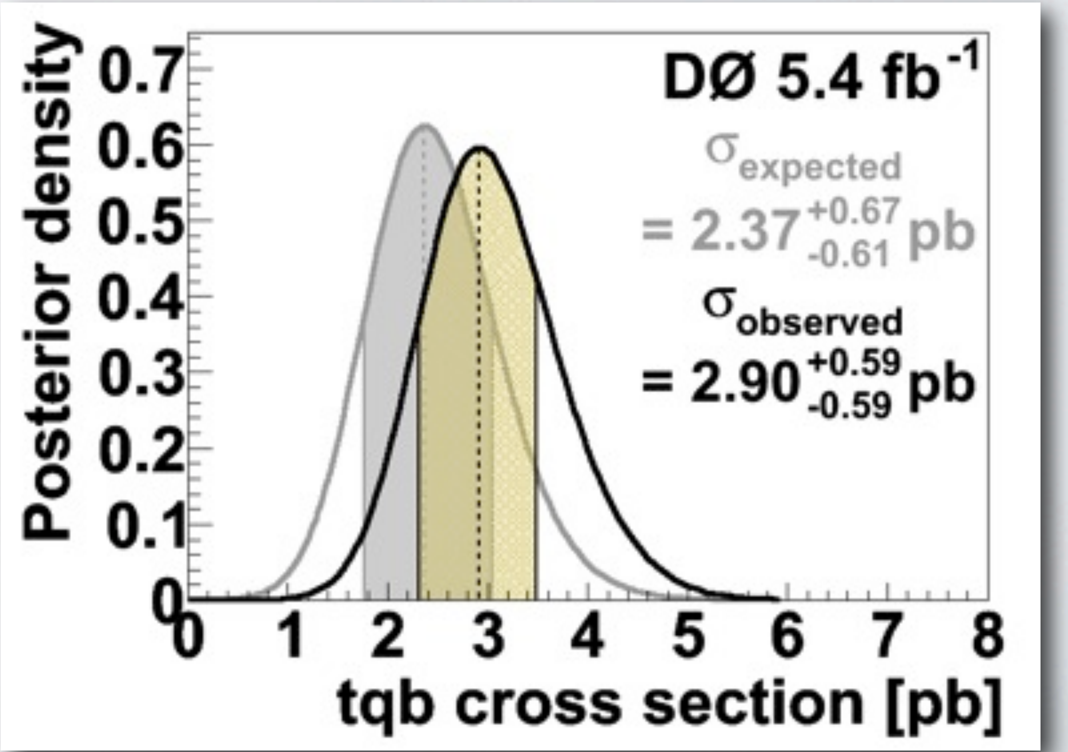
t-channel cross section without assuming SM s-channel

- A 2D Bayesian posterior probability density is computed.
- A 1D posterior density can be obtained by integrating over the s-channel xsection.
- The estimated significance for this result is larger than five standard deviations.
- The total relative error of 20% with a systematic uncertainty of 11%.

arXiv:1105.2788 submitted to Phys Lett B







Search of CP violation is single top production

- We know how to measure the single top cross section.
- We can then divide the analysis in two extra channels, one with positive and the other with negative charged leptons.
- We can use the lepton charge to identify those events from single top or anti-top production.
- We can then define the following asymmetry as

$$\mathcal{A} = \frac{\sigma(p\bar{p} \to tX)\mathcal{B}(t \to bW^+) - \sigma(p\bar{p} \to \bar{t}X)\mathcal{B}(\bar{t} \to \bar{b}W^-)}{\sigma(p\bar{p} \to tX)\mathcal{B}(t \to bW^+) + \sigma(p\bar{p} \to \bar{t}X)\mathcal{B}(\bar{t} \to \bar{b}W^-)}.$$

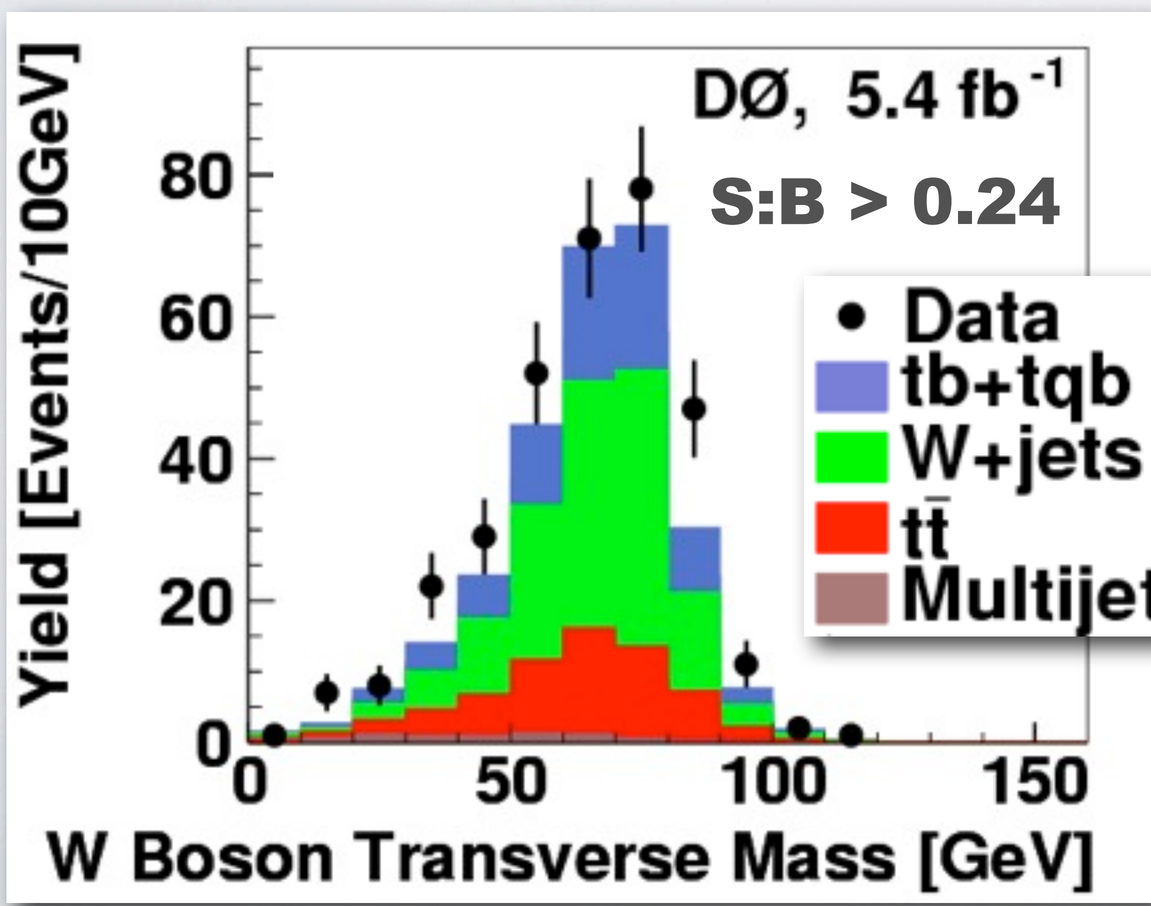
- Additional systematic are the lepton charge misidentification and the different calorimeter responses for c/cbar or b/bar jets.
- Lepton charge misidentification is estimated to be less that 1% using Z+jets events decaying to pairs of electrons or muons.
- The difference in the calorimeter responses for b/bar jets is estimated to be ~ 0.4% using tag and prove method in bbar dijets events.

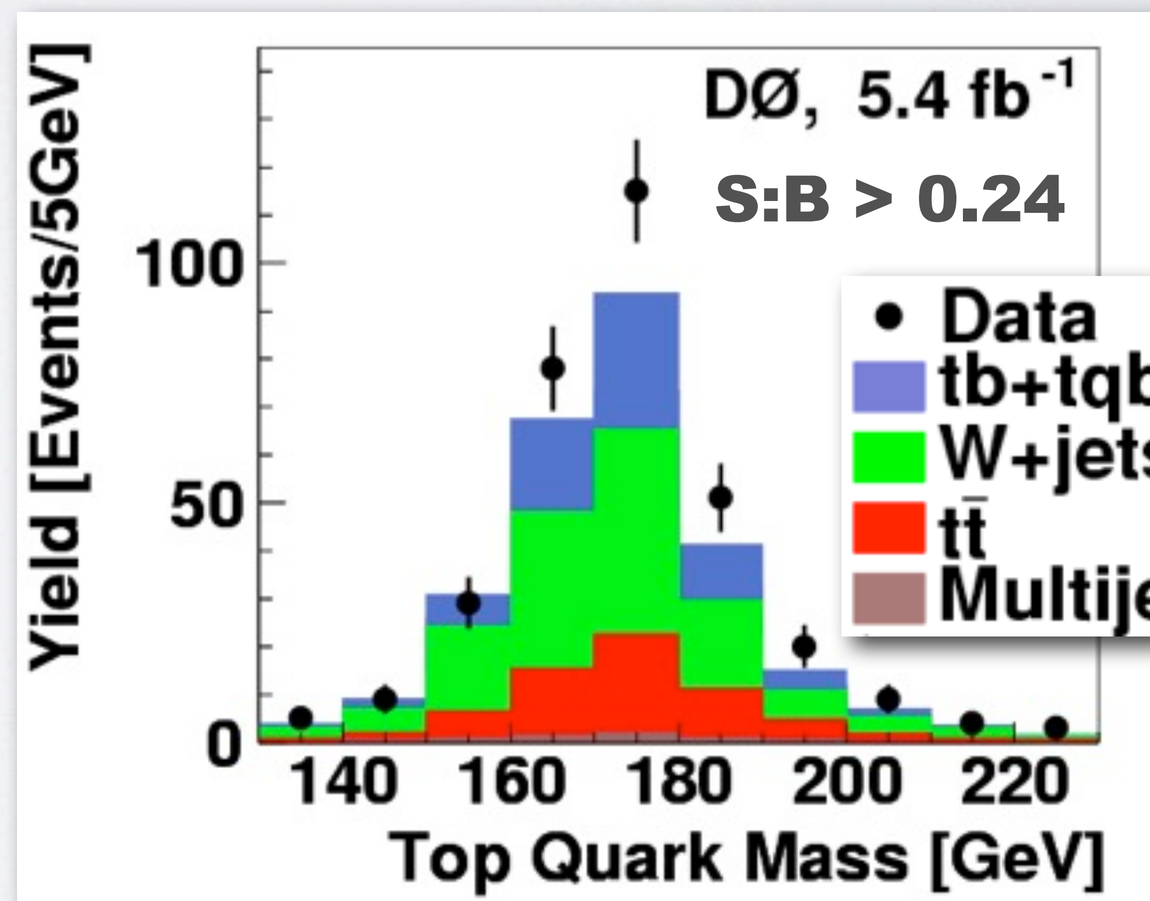
Search of CP violation is single top production

- From Phys. Rev. D **54**, 5412:

  "...Thus the asymmetries, in the range of a few percent, resulting from some extensions of the SM may well become within the reach of experiment **provided that the signal for these single top events could be extracted from possible backgrounds [18].**"

- This cannot be done by cutting in the single top discriminant.





Defining a posterior probability for the asymmetry

- The mean event counts with positive and negative lepton charges are

$$\overbrace{d_p}^{\text{positive and negative discriminant}} = \overbrace{\sigma_+}^{\text{positive and negative single top xsections}} a_p + b_p$$

$$d_n = \sigma_- \underbrace{a_n}_{\text{positive and negative acceptance}} + \underbrace{b_n}_{\text{positive and negative background events}}$$

$$p(\sigma_+, \sigma_-)$$

- Change of variables to total xsection and xsection asymmetry

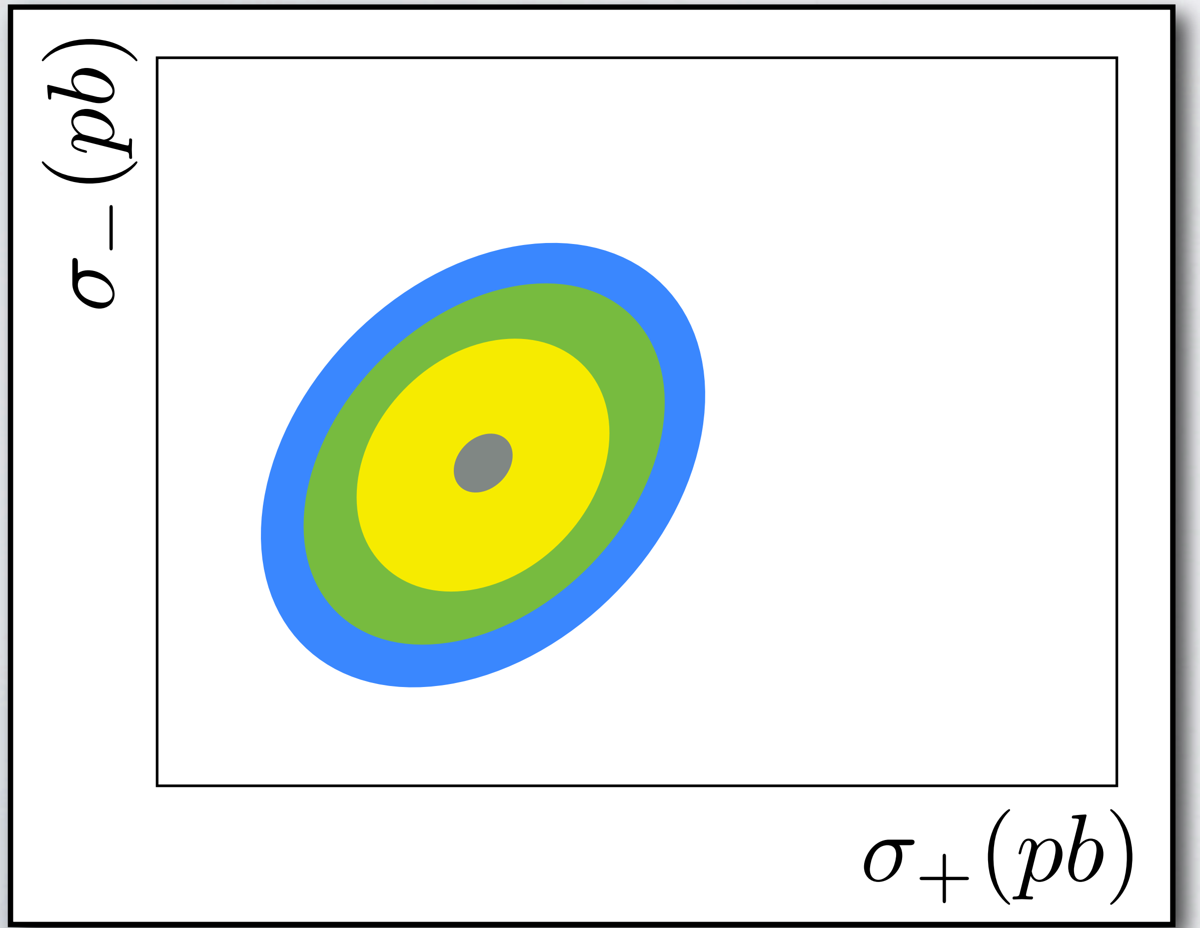
Total xsection

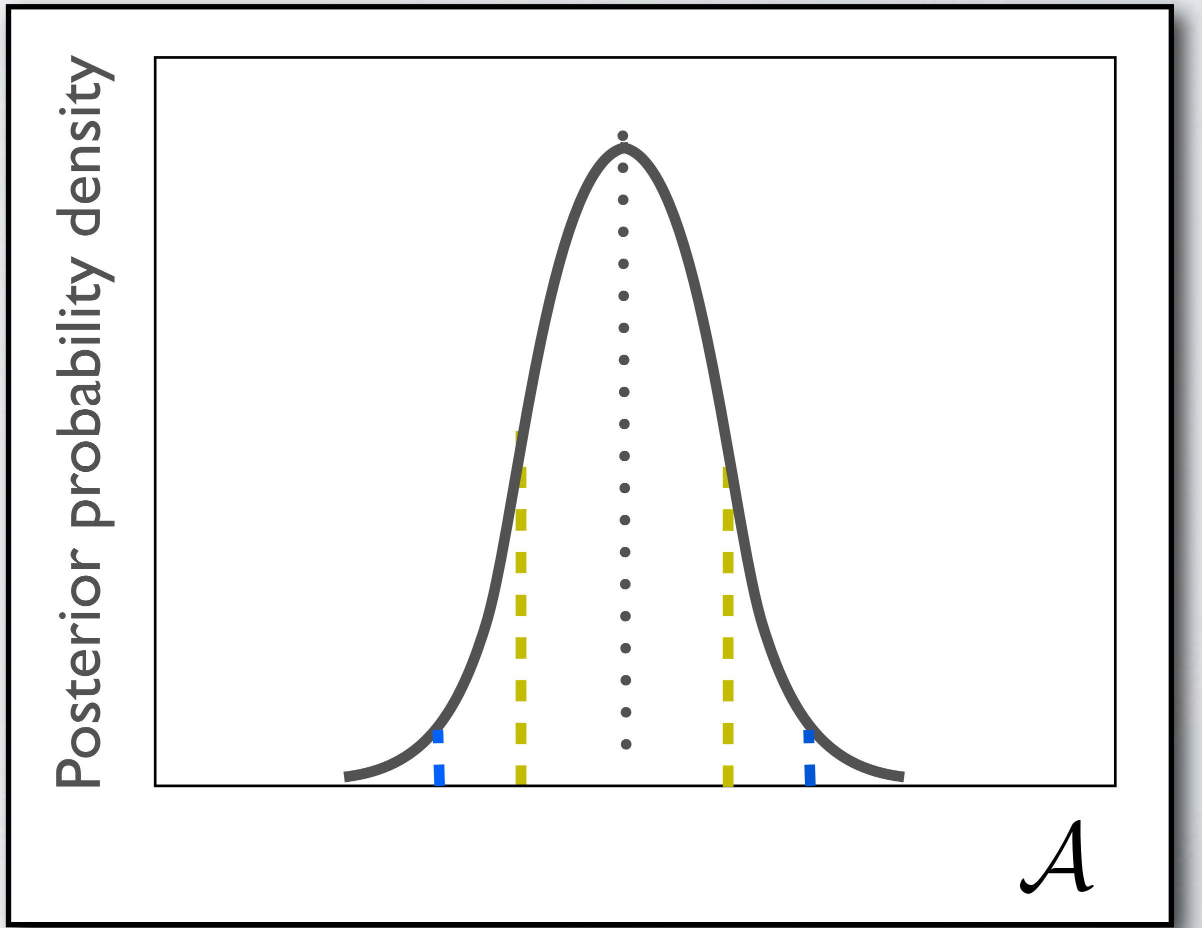
$$\sigma = \sigma_+ + \sigma_-$$

$$\mathcal{A} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

Xsection asymmetry

$$p(\mathcal{A}) = \int p(\sigma, \mathcal{A}) d\sigma$$



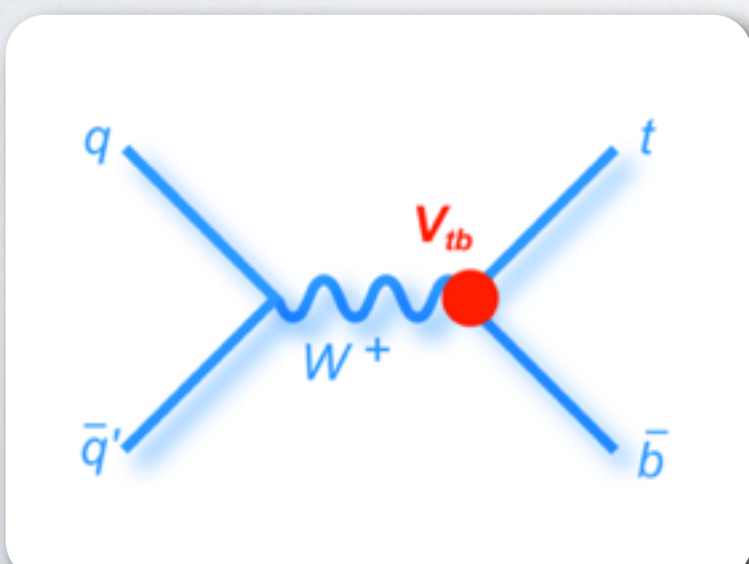


Asymmetry for difference sources of single top

- It is assumed that all the background do not violate CP.
- We can measurement asymmetry for events from single top s+t-channel production.
- Also it is possible to the measurement of the asymmetry for events from single top t-channel assuming no violation in s-channel.
- ... and the asymmetry for events from single top s-channel assuming no violation in t-channel.

Summary

- We show new results for cross section at the Tevatron for a integrated luminosity of 5.4 ifb.
- Present method to measure the cross section for the electron weak production of tops and antitops.
- We are expecting to use the full D0 dataset to measure the asymmetry for single top and antitop production.



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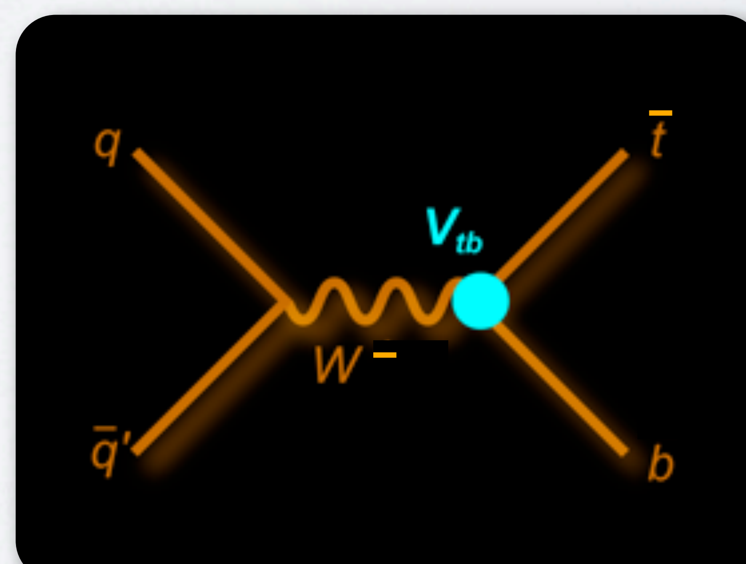


?

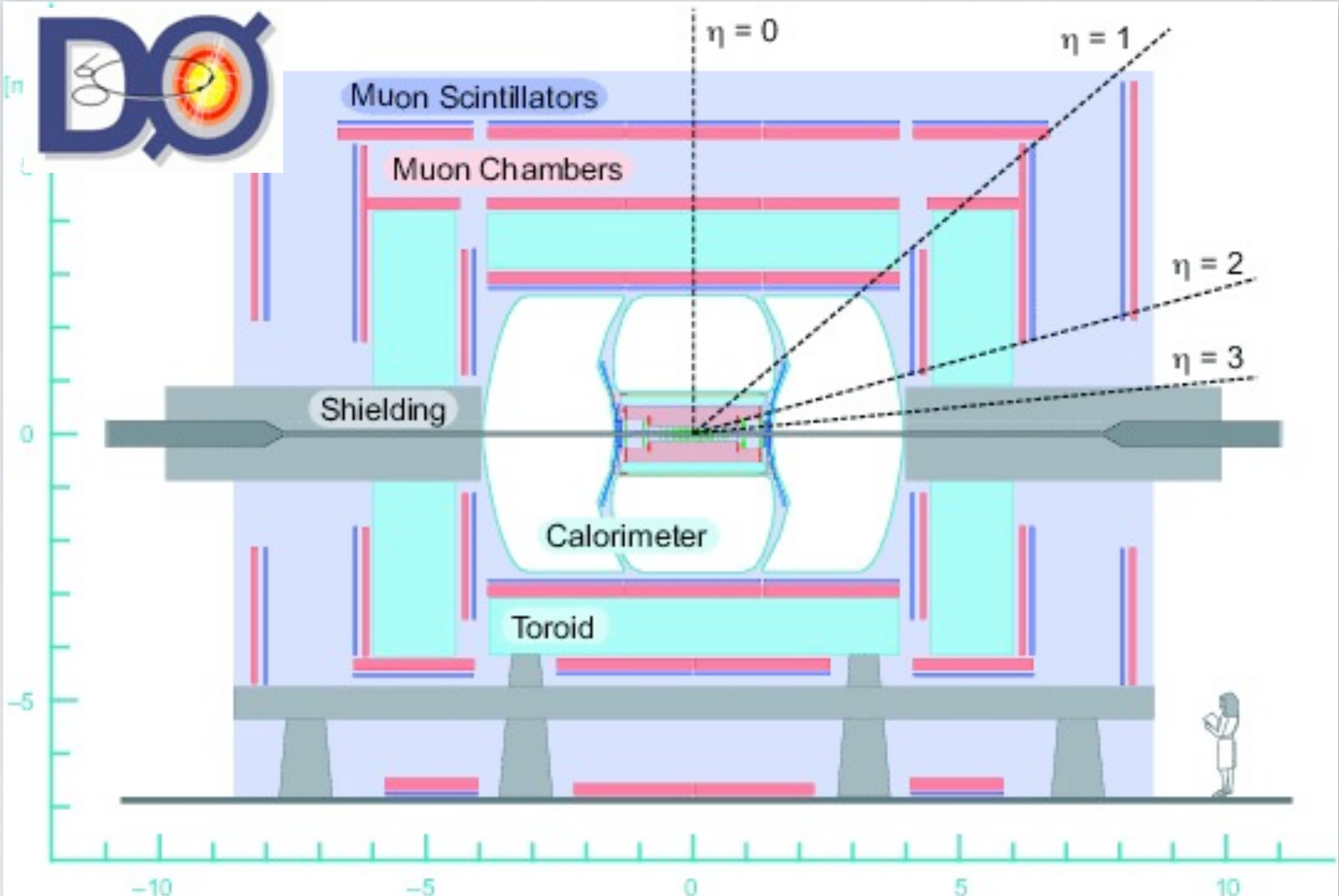
BACKUP SLIDES

The Tevatron accelerator

- Tevatron collider.
  - Proton-antiproton collider with $\sqrt{s}$=1.96 TeV
  - 36x36 bunches with 396 ns between crossings
  - ~5 collisions per bunch crossing
  - Inst luminosity ~$3 \times 10^{32} cm^{-2} s^{-1}$
- Run I 1992-1995.
  - Top quark observed!
- Run II 2001-2011.
  - Single top quark observed.
  - Hopefully more exciting physics results.

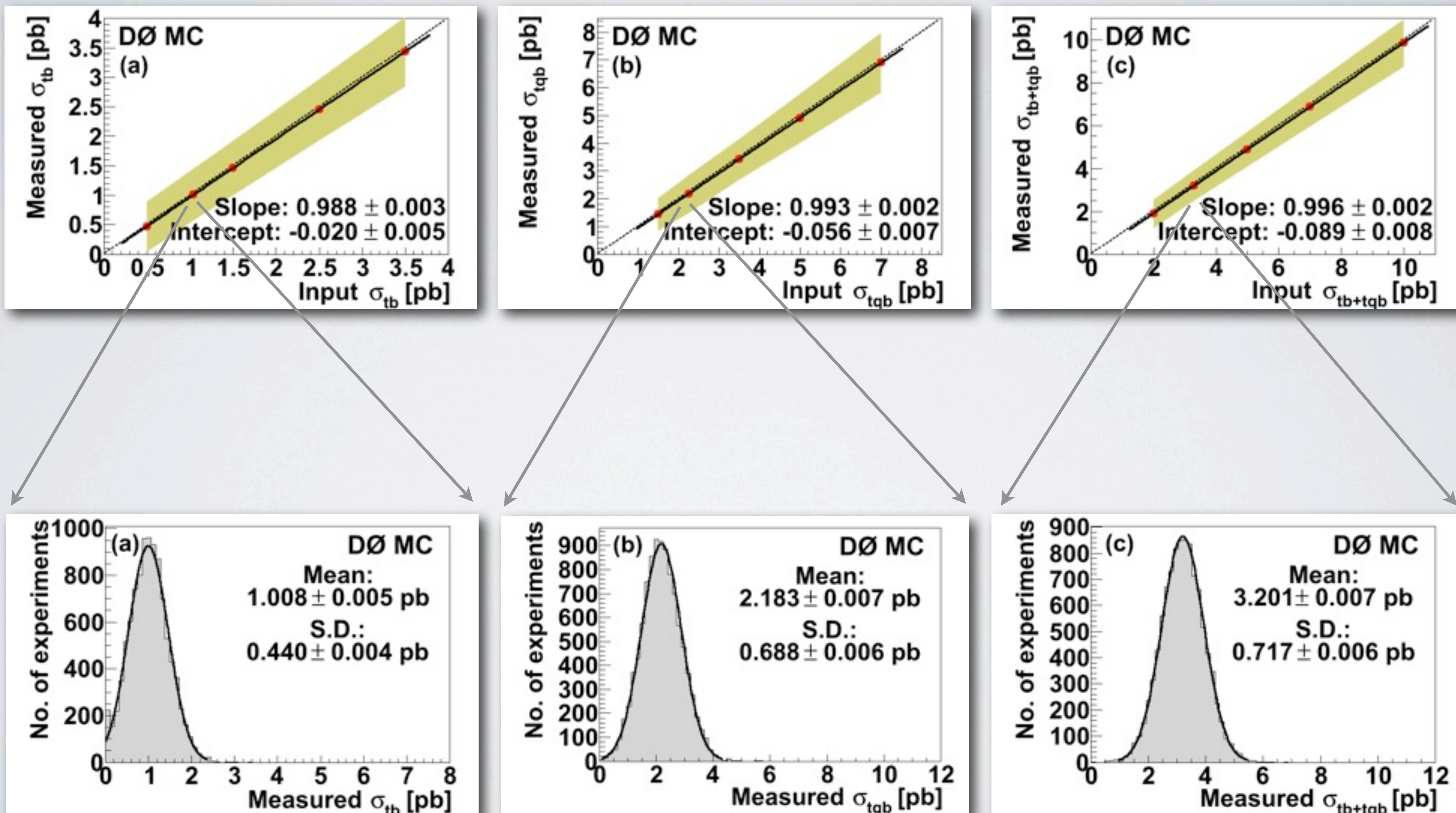
- Tevatron is running at peak performance!
  - ~ 10/fb per experiment.
  - ~ 12/fb by end of 2011.

The D0 detectors



- **Tracking**
  - Momentum measurement of charged particles.
  - Vertex and b-jet identification
- **Calorimeter**
  - Energy measurement of jets, electrons and neutrinos.
- **Muon system**
  - Momentum measurement of muons
- **Three level trigger system.**

Linearity Test and Ensemble Distribution



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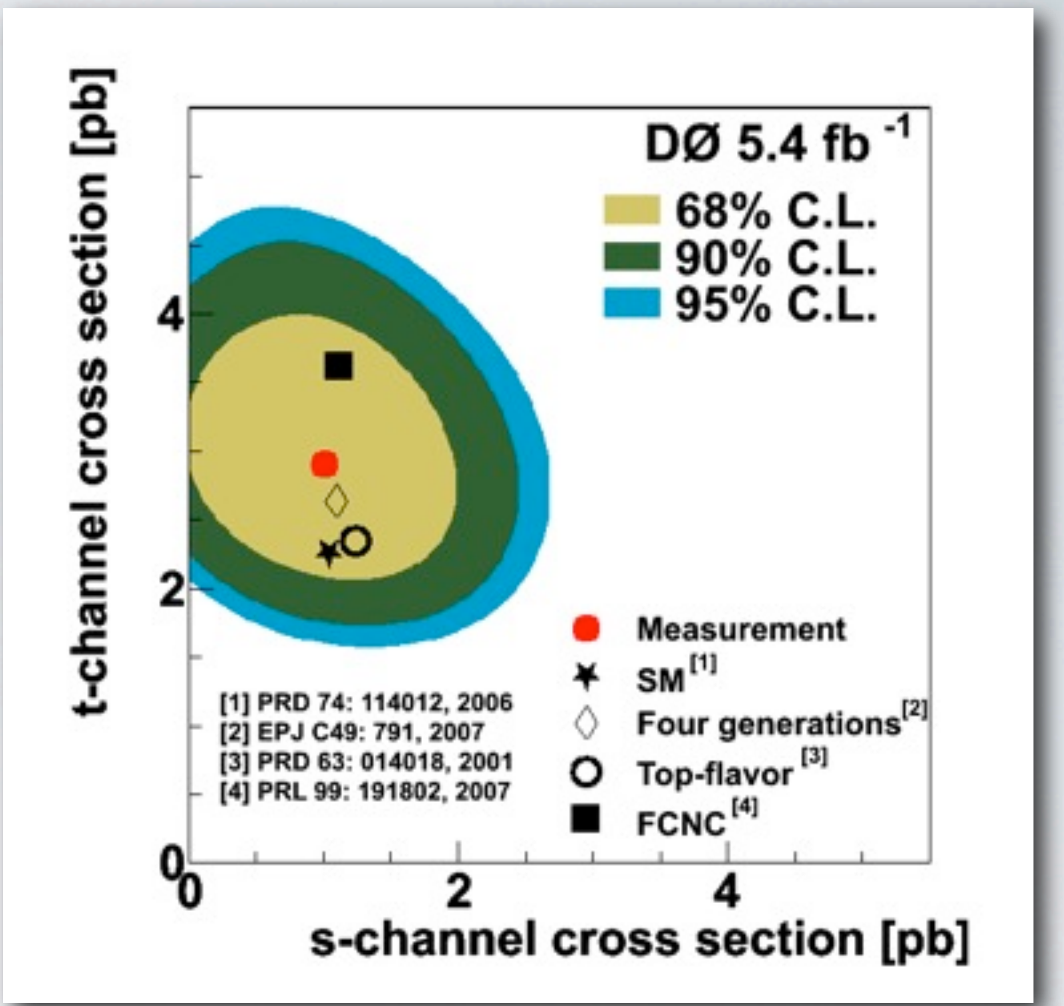
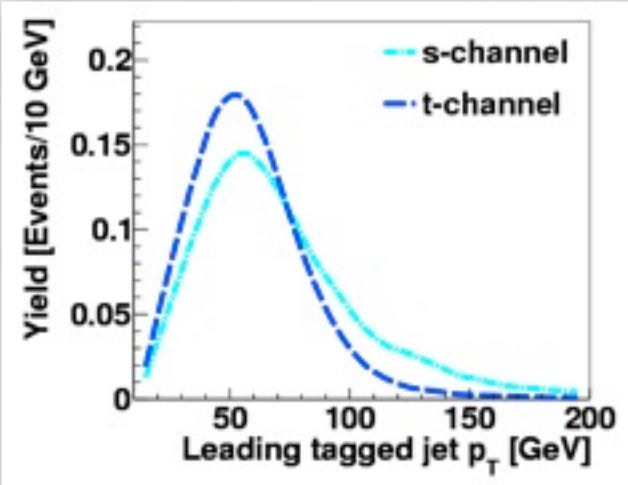
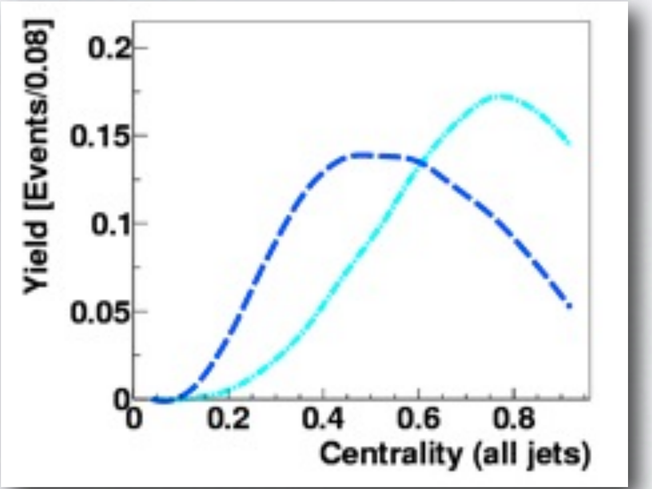
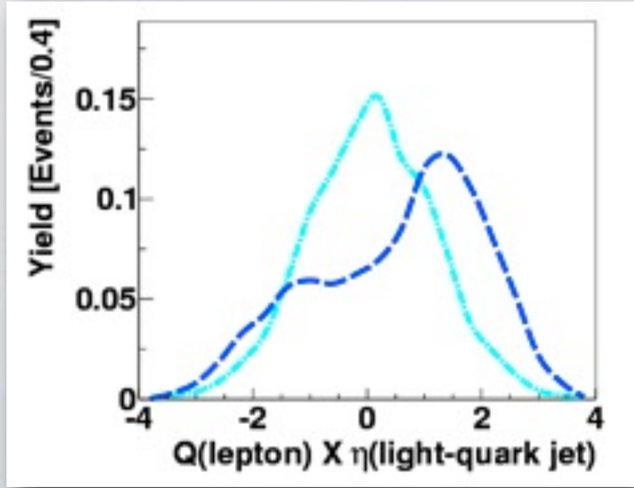
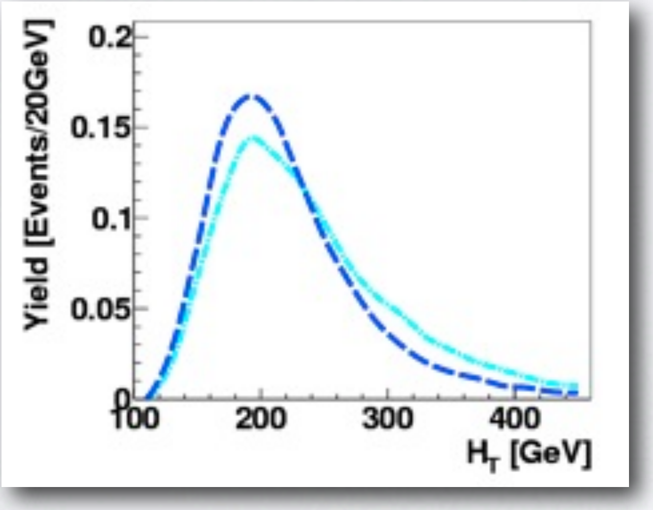
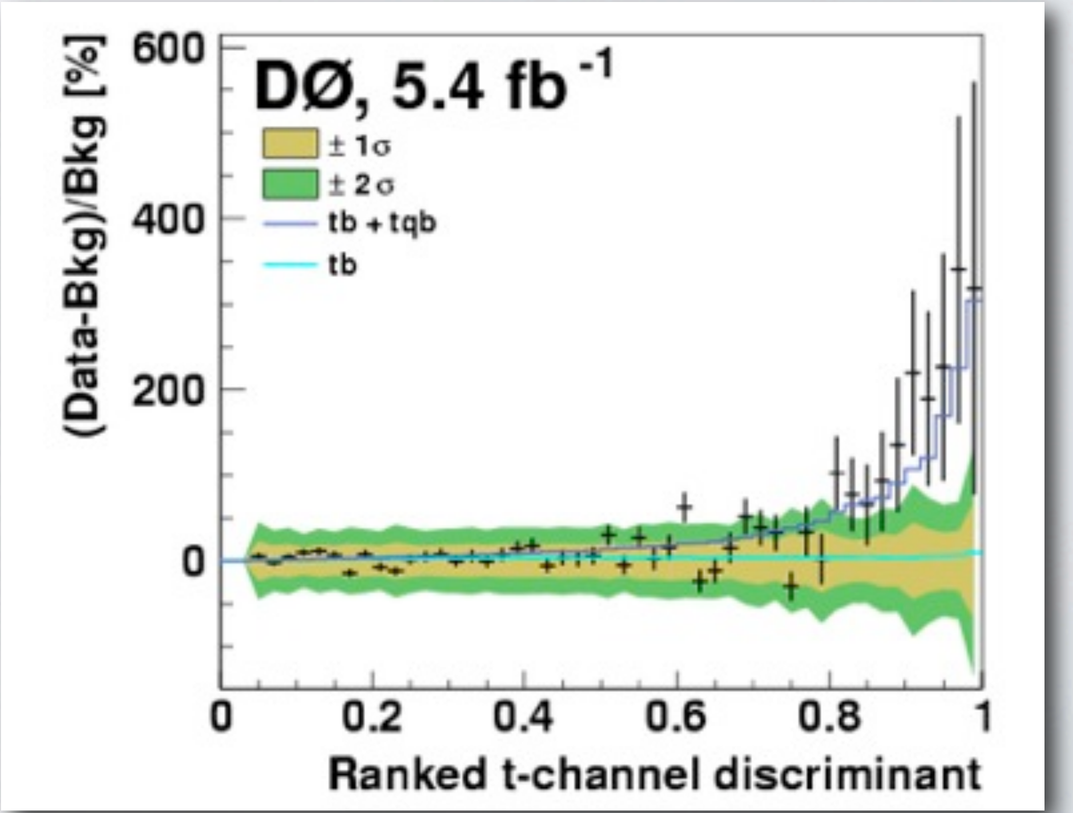




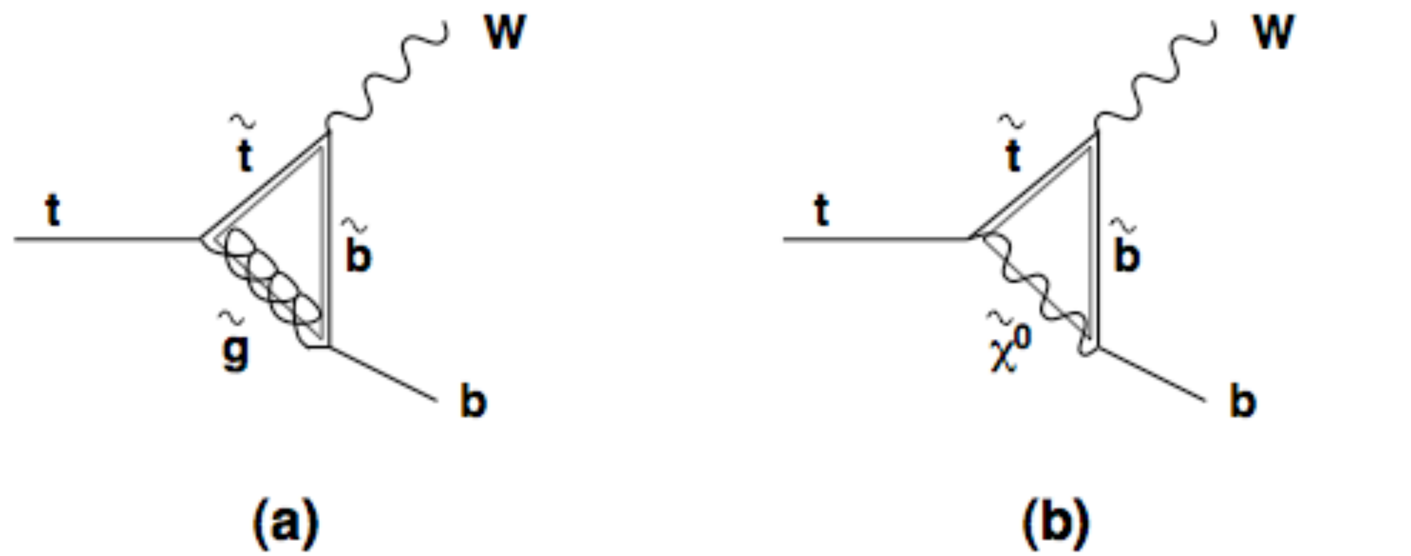








SUSY CPV 1-loop for top quark decay



Phys.Rept. 347, 1 (2001), arXiv:hep-ph/0006032

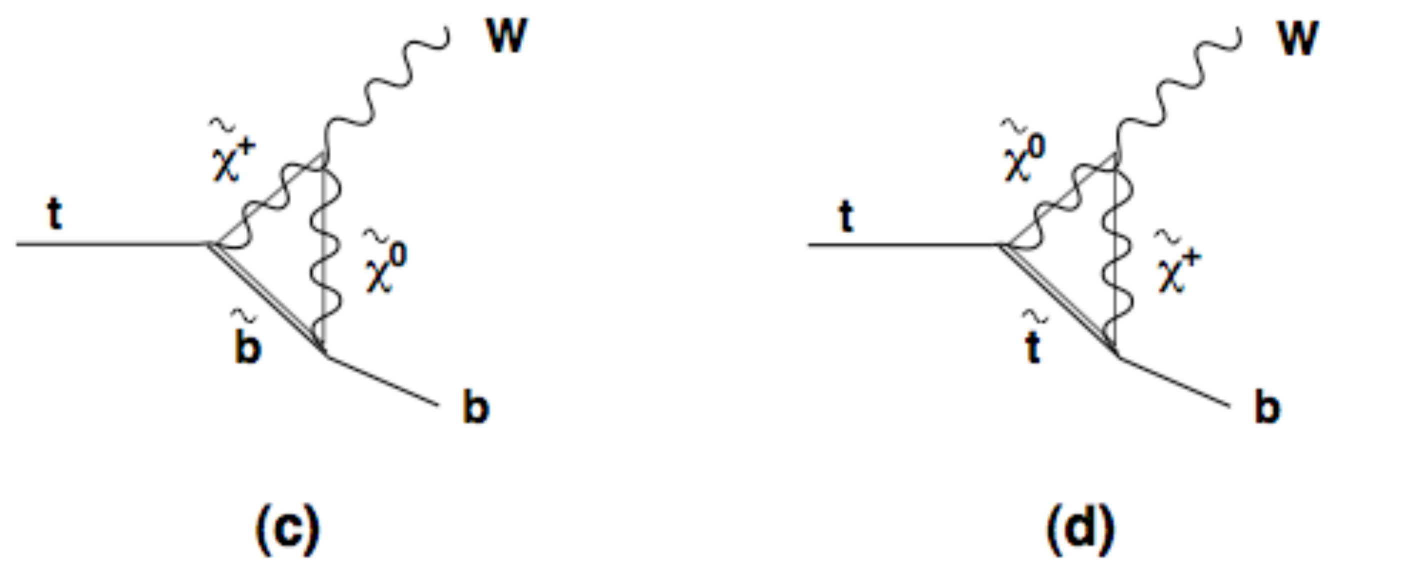


Figure 23: *The SUSY induced 1-loop Feynman diagrams that contribute to CP violation in the main top decay $t \to bW$. $\tilde{\chi}$ is the chargino, $\tilde{\chi}^0$ is the neutralino, $\tilde{g}$ is the gluino and $\tilde{t}, \tilde{b}$ are the stop and sbottom particles, respectively.*

2HDM CPV for single top quark production

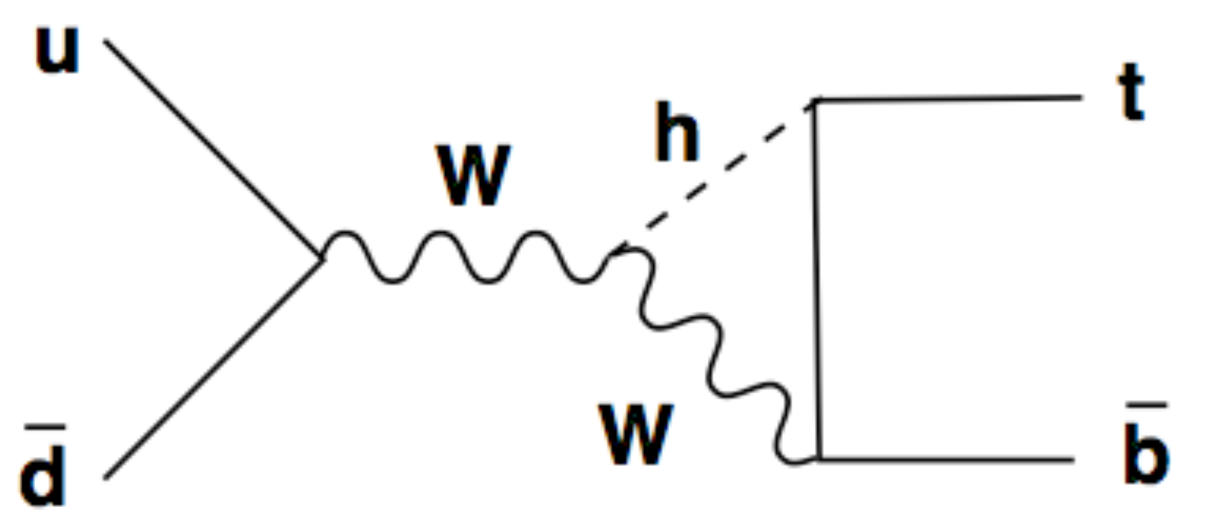
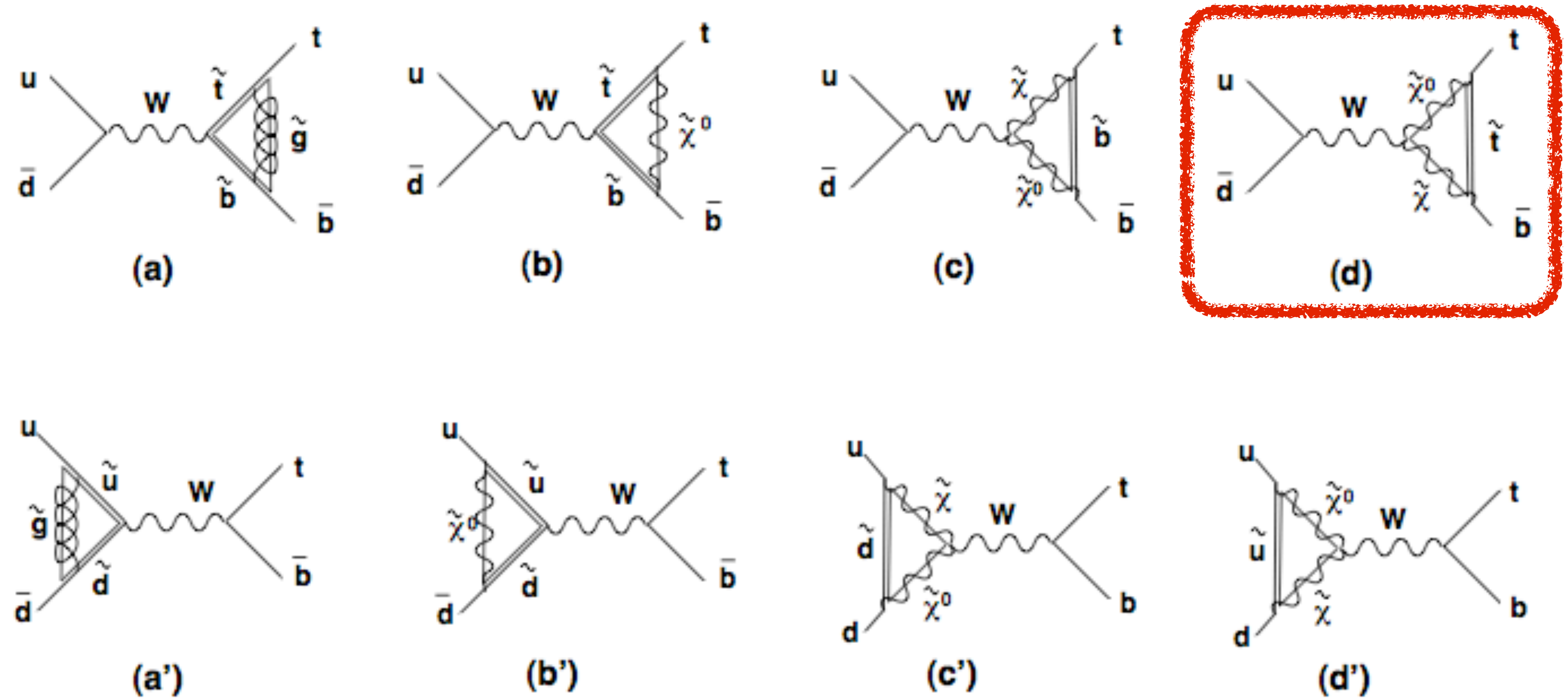


Figure 55: *The CP-violating 1-loop graph in 2HDM's with CP violation from neutral Higgs exchanges; h denotes the lightest neutral Higgs.*

Phys.Rept. 347, 1 (2001), arXiv:hep-ph/0006032

SUSY CPV 1-loop for single top quark production



Phys.Rept. 347, 1 (2001), arXiv:hep-ph/0006032

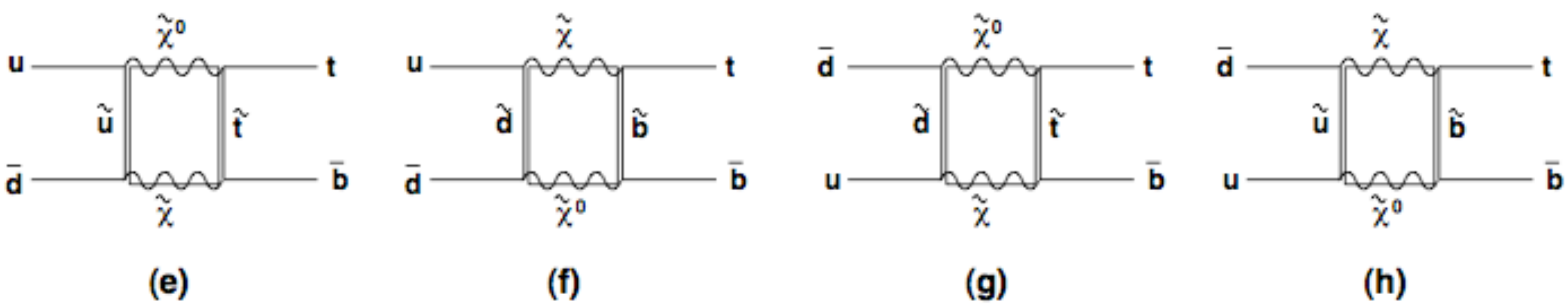


Figure 57: *CP-violating, SUSY induced, 1-loop diagrams for the processes* $u\bar{d} \to t\bar{b}$. $\tilde{g}$ *is the gluino,* $\tilde{\chi}$ *is a chargino,* $\tilde{\chi}^0$ *is a neutralino and* $\tilde{t}$ *and* $\tilde{b}$ *are top and bottom squarks, respectively.*

Measuring cross section

Binned likelihood

$$L(\mathbf{D}|\mathbf{d}) = \prod_{i=1}^{M} \frac{e^{d_i} d^{D_i}}{\Gamma(D_i+1)}$$

Mean event count

$$\mathbf{d} = \sigma \underbrace{\mathbf{a}}_{\text{signal acceptances}} + \underbrace{\mathbf{b}}_{\text{background event yields}}$$

Bayes' Theorem

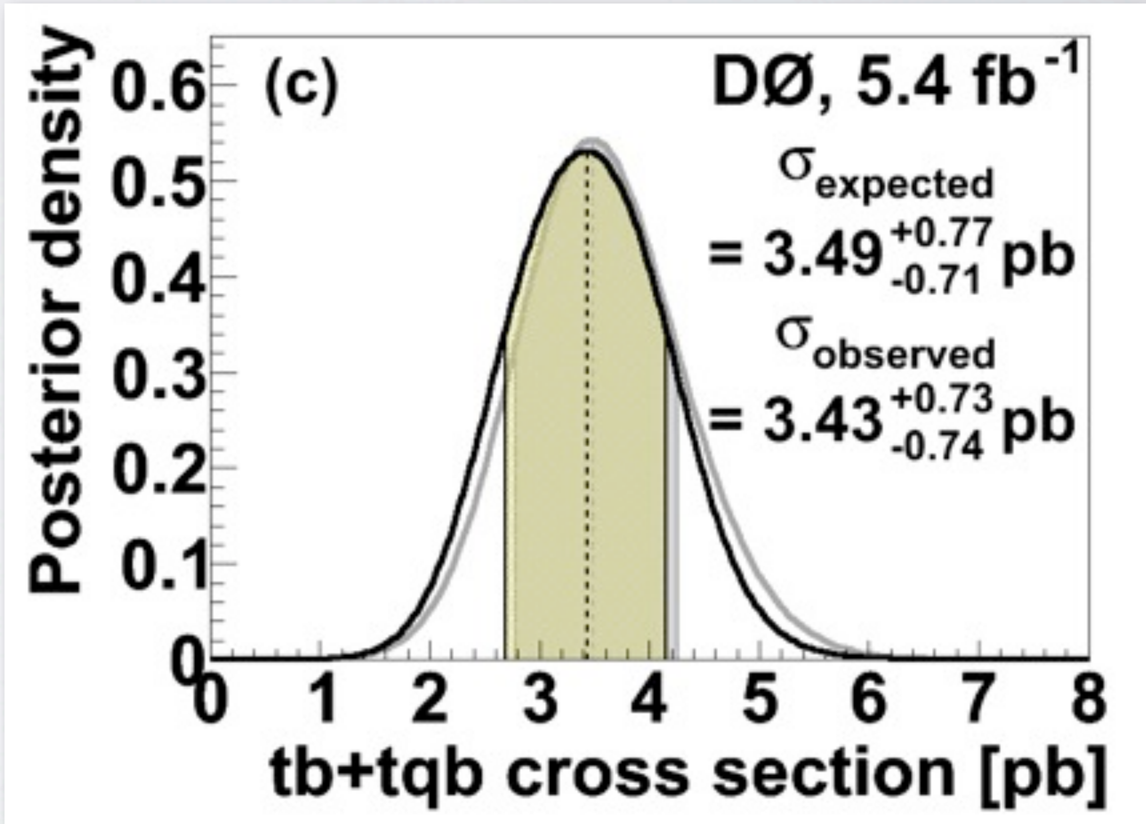
$$p(\sigma|\mathbf{D}) = \frac{1}{\mathcal{N}} \int L(\mathbf{D}|\sigma,\mathbf{a},\mathbf{b}) \pi(\sigma,\mathbf{a},\mathbf{b}) d\mathbf{a} d\mathbf{b}$$

Assuming nonnegative flat prior

$$p(\sigma|\mathbf{D}) = \frac{1}{\mathcal{N}\sigma_{\max}} \int L(\mathbf{D}|\sigma,\mathbf{a},\mathbf{b}) \pi(\mathbf{a},\mathbf{b}) d\mathbf{a} d\mathbf{b}$$

Numerical integration

$$p(\sigma|\mathbf{D}) \propto \int L(\mathbf{D}|\sigma,\mathbf{a},\mathbf{b}) \pi(\mathbf{a},\mathbf{b}) d\mathbf{a} d\mathbf{b}$$
$$\approx \frac{1}{K} \sum_{k=1}^{K} L(\mathbf{D}|\sigma,\mathbf{a}_k,\mathbf{b}_k)$$



Defining a posterior probability for the asymmetry

- We measure the single top cross sections for events with positive and negative lepton charges

$$L(\mathbf{D}|\sigma_+,\sigma_-,\mathbf{a},\mathbf{b}) = \prod_{p=1} \frac{e^{-d_p} d_p^{D_p}}{\Gamma(D_p+1)} \prod_{n=1} \frac{e^{-d_n} d_n^{D_n}}{\Gamma(D_n+1)}$$

- The mean event counts with positive and negative lepton charges are

$$d_p = \sigma_+ a_p + b_p$$
$$d_n = \sigma_- a_n + b_n$$

- Then it is possible to define a 2D posterior distribution after integrating over all the systematic uncertainties

$$p(\sigma_+,\sigma_-) = \frac{1}{\mathcal{N}} \int L(\mathbf{D}|\sigma_+,\sigma_-,\mathbf{a},\mathbf{b})\pi(\sigma_+,\sigma_-)\pi(\mathbf{a},\mathbf{b})d\mathbf{a}d\mathbf{b}.$$

- This distribution can then be written as a function of the total cross section and the asymmetry

$$p(\sigma,\mathcal{A}) = \frac{\sigma}{2\mathcal{N}} \int L(\mathbf{D}|\sigma(1+\mathcal{A})/2,\sigma(1-\mathcal{A})/2,\mathbf{a},\mathbf{b})\pi(\sigma,\mathcal{A})\pi(\mathbf{a},\mathbf{b})d\mathbf{a}d\mathbf{b}$$

- The total cross section and asymmetry is defined as

$$\sigma = \sigma_+ + \sigma_- \qquad \mathcal{A} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- A posterior probability density is defined by

$$p(\mathcal{A}) = \int p(\sigma,\mathcal{A})d\sigma$$

CP violation in single top production and decay

$$\mathcal{A} = \frac{\sigma(p\bar{p} \to tX)\mathcal{B}(t \to bW^+) - \sigma(p\bar{p} \to \bar{t}X)\mathcal{B}(\bar{t} \to \bar{b}W^-)}{\sigma(p\bar{p} \to tX)\mathcal{B}(t \to bW^+) + \sigma(p\bar{p} \to \bar{t}X)\mathcal{B}(\bar{t} \to \bar{b}W^-)}.$$

Because of CPT is possible to rewrite the asymmetry as

$$\mathcal{A} = \frac{\sigma(p\bar{p} \to tX)\Gamma(t \to bW^+) - \sigma(p\bar{p} \to \bar{t}X)\Gamma(\bar{t} \to \bar{b}W^-)}{\sigma(p\bar{p} \to tX)\Gamma(t \to bW^+) + \sigma(p\bar{p} \to \bar{t}X)\Gamma(\bar{t} \to \bar{b}W^-)}$$

Factorizing the asymmetry in terms of the single top quark production and decay:

$$\mathcal{A} = \frac{\mathcal{A}_P + \mathcal{A}_D}{1 + \mathcal{A}_P \mathcal{A}_D}$$

$$\mathcal{A}_P = \frac{\sigma(p\bar{p} \to tX) - \sigma(p\bar{p} \to \bar{t}X)}{\sigma(p\bar{p} \to tX) + \sigma(p\bar{p} \to \bar{t}X)}. \qquad \mathcal{A}_D = \frac{\Gamma(t \to bW^+) - \Gamma(\bar{t} \to \bar{b}W^-)}{\Gamma(t \to bW^+) + \Gamma(\bar{t} \to \bar{b}W^-)}$$

Search of CP violation is single top production

- From Phys. Rev. D **54**, 5412:

  "...Thus the asymmetries, in the range of a few percent, resulting from some extensions of the SM may well become within the reach of experiment **provided that the signal for these single top events could be extracted from possible backgrounds [18].**"

  [18]: We note that experimental issues such as detector efficiencies, backgrounds and the like are clearly very important on their own right, requiring extensive studies that are beyond the scope of this work.

Search of CP violation is single top production

- From Phys. Rev. D **65**, 094002 (arXiv:hep-ph/0108076):

  "...To measure an asymmetry of the order of 10−4, one would need about 108 events. This is far beyond the observability of such an asymmetry at the Tevatron. Nevertheless, it would be worthwhile to look for CP violation in top physics as it would imply not only physics beyond the Standard Model, **but also beyond the Minimal Supersymmetric Standard Model.**"